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ELECTRONIC DESIGN PROCESS

Charles T. Kitzmiller  
Michael A. Anderson

Boeing Computer Services  
Advanced Technology Center  
P.O. Box 24346, M.S. 7L-64  
Seattle, Washington 98124-0346

LOGISTICS AND HUMAN FACTORS DIVISION  
Wright-Patterson Air Force Base, Ohio 45433-6503

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LABORATORY

AIR FORCE SYSTEMS COMMAND  
BROOKS AIR FORCE BASE, TEXAS 78235-5601

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Logistics and Human Factors Division

JAMES C. CLARK, Colonel, USAF  
Chief, Logistics and Human Factors Division

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**Charles T. Kitzmiller**  
**Michael A. Anderson**

**Boeing Computer Services  
Advanced Technology Center  
P.O. Box 24346, M.S. 7L-64  
Seattle, Washington 98124-0346**



**LOGISTICS AND HUMAN FACTORS DIVISION**  
**Wright-Patterson Air Force Base, Ohio 45433-6503**

**Wendy B. Campbell**  
**Chief, Logistics Systems Branch**

**Bertram W. Cream, Technical Director**  
**Logistics and Human Factors Division**

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## SUMMARY

To achieve the goals of Department of Defense (DoD) programs such as Reliability and Maintainability (R&M) 2000 the Air Force needs to greatly improve weapon system designs. To help meet these program goals and improve weapon system designs, the Air Force Human Resources Laboratory (AFHRL) embarked on the Reliability, Availability, and Maintainability in Computer-Aided Design (RAMCAD) effort. The RAMCAD effort is aimed at creating a design environment that fully supports reliability, maintainability, and supportability (RM&S) issues through the use of computer-aided design/computer-aided engineering (CAD/CAE) workstations. The goal of the Boeing Computer Services (BCS) contract is to create a design methodology that will allow weapon system designers to better integrate RM&S issues and requirements in to weapon system designs.

This paper covers a major section of the research performed during the first year of the BCS RAMCAD contract. This paper documents the design cycle of a generic avionics system for military applications. BCS attempts to do this in such a way that it may be applicable to any company designing avionics devices for the military. The research documented in this paper includes only what is currently done and does not attempt to state where changes can be made to improve how RM&S is implemented in system design. In addition, it does not just focus on the parts of the design cycle that currently include the use of CAD/CAE workstations but attempts to cover the complete design cycle from system level requirements analysis through detailed design and design evaluation. This paper was created to allow BCS to determine where changes are required in the design cycle to allow for true design optimization.

## PREFACE

In September 1987, the Air Forces Human Resources Laboratory (AFHRL) awarded Boeing Computer Services (BCS) contract F33615-87-C-0001 to perform long-term research associated with the Reliability, Availability, and Maintainability in Computer-Aided Design (RAMCAD) effort. The goal of the contract is to create a design optimization methodology as well as proof-of-concept software tools for a computer-aided design/computer-aided engineering (CAD/CAE) workstation to implement the methodology. BCS is focusing its efforts on optimizing an electronic design for reliability, testability, performance, and cost and area resources.

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## 1.0 INTRODUCTION

This paper summarizes the initial results of Task 3.3.2.1, "Design Process Definition," Reliability, Availability, and Maintainability in Computer-Aided Design (RAMCAD) Statement of Work (SOW) (U. S. Air Force contract F33615-87-C-0001) (Reference 1). In this task, we described and analyzed the process currently employed to design avionic systems for military applications. The purpose of this task was to develop the information and understanding needed to identify problems (deficiencies and limitations) in the current design process, design methods, and associated analytical methods.

This task is part of RAMCAD SOW Task 3.3.2, "Requirements Analysis," which defines the needs associated with designing avionic systems for improved reliability, maintainability, and supportability (RM&S). The information developed in Task 3.3.2 is intended to support subsequent efforts to determine specific areas in which decision support capabilities for design and improved RM&S analytical tools are needed. Task 3.3.2.1 supports that objective by providing a detailed description of the specific tasks and analyses that are most often employed in the existing design process.

In conjunction with determining existing RM&S analysis needs (Task 3.3.2.2, "Identify RM&S Technology Needs") and analyzing existing computer-aided design tools (Task 3.3.3, "Analysis of CAD Tools"), Task 3.3.2.1 supports the development of requirements that will focus the research to be conducted during the RAMCAD program at Boeing Computer Services.

### 1.1 TECHNICAL APPROACH

Section 4.2 of the RAMCAD Software Development Program Detailed Research Plan (Reference 2) outlines the basic approach used to develop the information contained in this paper.

This information was obtained from two primary sources: (a) interviews with senior engineers involved in the design of avionic systems within The Boeing Company and (b) a review of DOD and Boeing design-related standards and documents.

Over 30 senior engineers were interviewed during the course of this research. Among them were specialists in a variety of design-related disciplines, including systems engineering, circuit design, packaging, design assurance (airworthiness), manufacturing, logistics support, and computer-aided engineering and computer-aided design (CAE/CAD) tool development. The individuals interviewed represent a number of active design projects, including the design of avionic systems and subsystems for the B-1B, the Advanced Tactical Fighter, the Small ICBM, and the Hard Mobile Launcher Weapons Control System. In addition to discussions with those involved in the design of military systems, limited discussions were held with individuals involved in the design of systems for commercial applications.

Individuals were selected to participate in the interview process based upon recommendations by their peers and the results of an initial screening interview. The selection process was heavily weighted toward those individuals recognized by the Boeing design community as particularly knowledgeable in some aspect of the avionics design process.

As noted in the research plan, the interviews were structured to acquire information in three areas—individual experience, avionics technology, and the avionics design process—and were oriented toward capturing knowledge in the area of the individual's expertise (e.g., systems engineering, detailed circuit design).

## 1.2 ORGANIZATION OF THE REPORT

The paper is organized into several major sections, as described in the following paragraphs.

Sections 2.0, 3.0, and 4.0 discuss the design process from the viewpoint of an evolving definition of the system to be designed. These sections provide a narrative "walk-through" of the design process, showing the sequence in which tasks are performed to develop a detailed description of an end item to be manufactured.

Section 2.0 describes the overall design process at a high level. It describes the basic design cycle employed throughout the design process and identifies the top-level tasks, their sequencing, and their key deliverables.

Sections 3.0 and 4.0 describe the systems engineering (Sec. 3.0) and detailed design (Sec. 4.0) phases of the design process in more detail. Section 3.0 covers the key design tasks from the initial system level requirements to the development of the requirements and specifications for an end item at the level of a line replaceable unit (LRU). It covers all tasks performed in the DOD conceptual design and development and concept demonstration and validation phases. Sec. 4.0 describes the primary design tasks involved in taking the definition of an LRU arrived at during the systems engineering phase and developing from it the engineering drawings and manufacturing dataset from which deliverable units are subsequently manufactured.

It should be noted that these sections focus on describing the process as it actually occurs within the aerospace industry. We have attempted to describe the constraints and pressures under which the process actually takes place.

Section 5.0 discusses some of the key design parameters and constraints considered in the trade studies.

Section 6.0 identifies and briefly discusses the problem areas, deficiencies, and bottlenecks associated with the current design process.

Appendix A describes in detail the relationships among design tasks.

Appendix B describes currently available design and analysis tools.

The appendixes, including individual task and tool descriptions, serve as reference data for later program tasks and contain more specific data about the various phases of the design process. These data are not repeated in the body of this paper, and it is assumed the reader will refer to the appendixes if additional detail is desired.

## **2.0 OVERVIEW OF THE DESIGN PROCESS**

The current design process generally yields successful designs that meet all applicable requirements and specifications. However the usual approach is one of satisficing (Reference 5), in that the goal is a design that meets the requirements rather than the best possible design. Although it is not clear that complete optimization is possible in solving a problem of the complexity of avionics design, the process can be modified to yield designs much closer to the optimum.

The basic process employed at Boeing to design avionics systems is modeled on the DOD Systems Engineering process described in Reference 4. Figure 1 indicates the major phases of this process and the phasing of the basic design activities.

### **2.1 BASIC DESIGN CYCLE**

At the core of the avionics design process is a basic design cycle. This cycle consists of a sequence of steps that are applied iteratively throughout the design process to develop successively more detailed requirements and descriptions of the item being designed. Although not always performed as separate tasks or conducted in a structured, explicit manner, this fundamental cycle is the basis for the overall design process.

This cycle consists of six major steps:

1. **Requirements analysis.** The mission and system requirements are analyzed to determine, in more detail, the functions needed to meet the mission and system requirements and specifications. Mission and system requirements are examined for validity, consistency, desirability, and attainability with respect to current technology, resources, life cycle costs, and other constraints. Where possible, quantifiable measures of performance are established to guide and evaluate the design.
2. **Functional analysis.** Each of the functions identified in Step 1 is decomposed into a set of primary subfunctions and the functional requirements applicable to each subfunction are derived. The primary tools of this step are functional flow diagrams appropriately annotated to identify and define the system operation and critical timing sequences.
3. **Functional allocation.** Functional block diagrams that define the architecture of the system are derived from the functional flow diagrams through a process in which each subfunction and its associated design requirements are allocated (assigned) to a functional block.
4. **Alternatives analysis and trade study.** Alternative means of implementing the required functions are proposed and evaluated against one another. This indicates the sensitivity of an alternative to the design criteria and the relative merits of each alternative. The alternatives typically include hardware and software technology, operational concepts, hardware concepts, vendors, and architectural alternatives for incorporating a technology.
5. **Synthesis.** A baseline system configuration is synthesized from the most promising elements of the alternatives identified in Step 4.
6. **Evaluation.** The baseline system configuration is evaluated against the requirements, and a decision is made about whether changes to the configuration are needed at this level or whether the design process can proceed to increasing levels of detail.

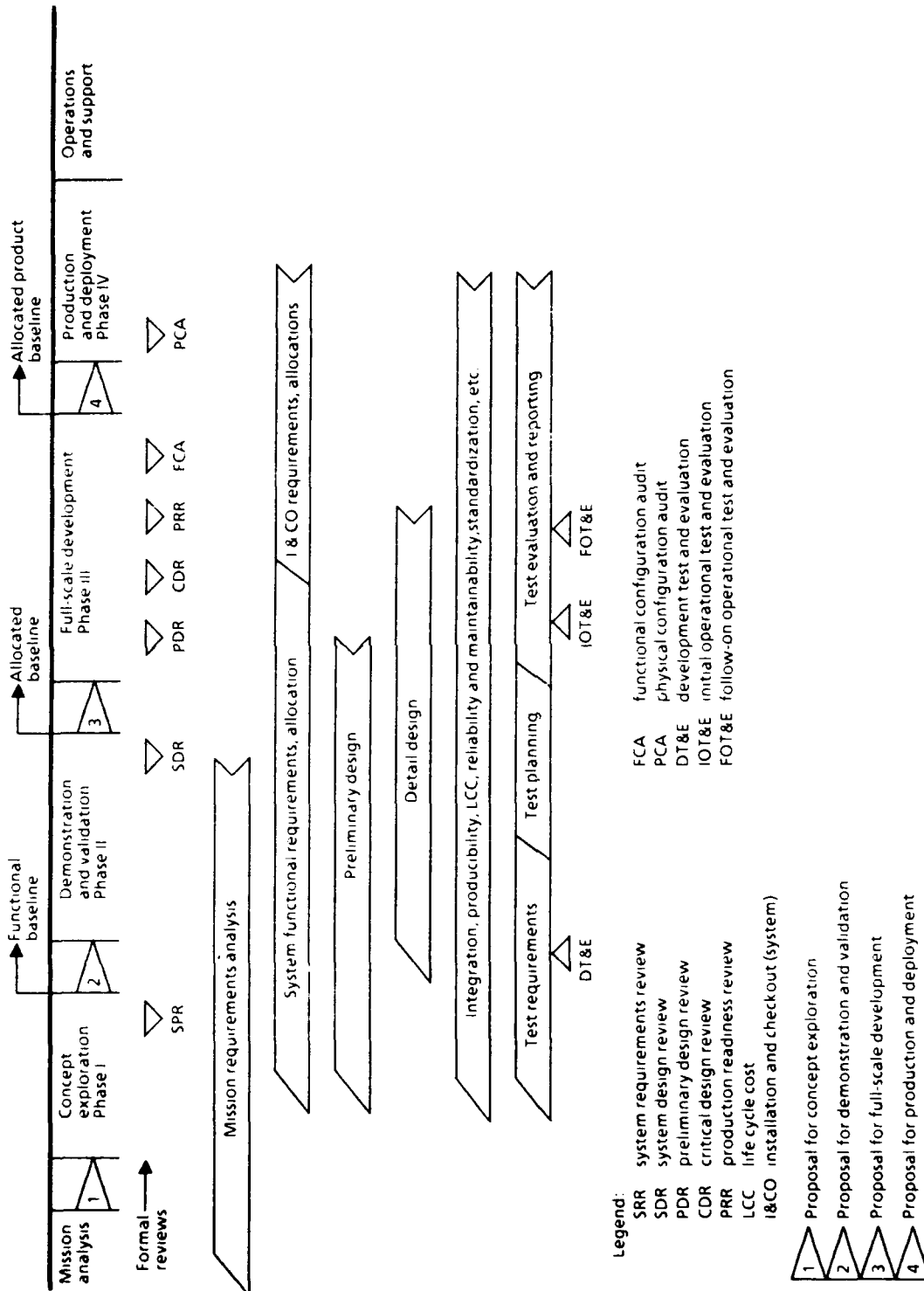


Figure 1. Systems Engineering Process Phasing for Major Technical Activities

## 2.2 BASIC AVIONICS SYSTEM DESIGN PROCESS

A top-level view of the design process is shown in Figure 2. At this level, the design process can be envisioned as consisting of five major tasks: (a) development of a baseline system design concept, (b) definition of a set of requirements for a deliverable end item about the size of a line replaceable unit (LRU), (c) design of the end item's basic circuit elements, (d) design of the end item's mechanical and electronic packaging (physical design), and (e) determination of the end item's manufacturing and producibility aspects. Figure 2 also shows the major deliverables between these top-level tasks.

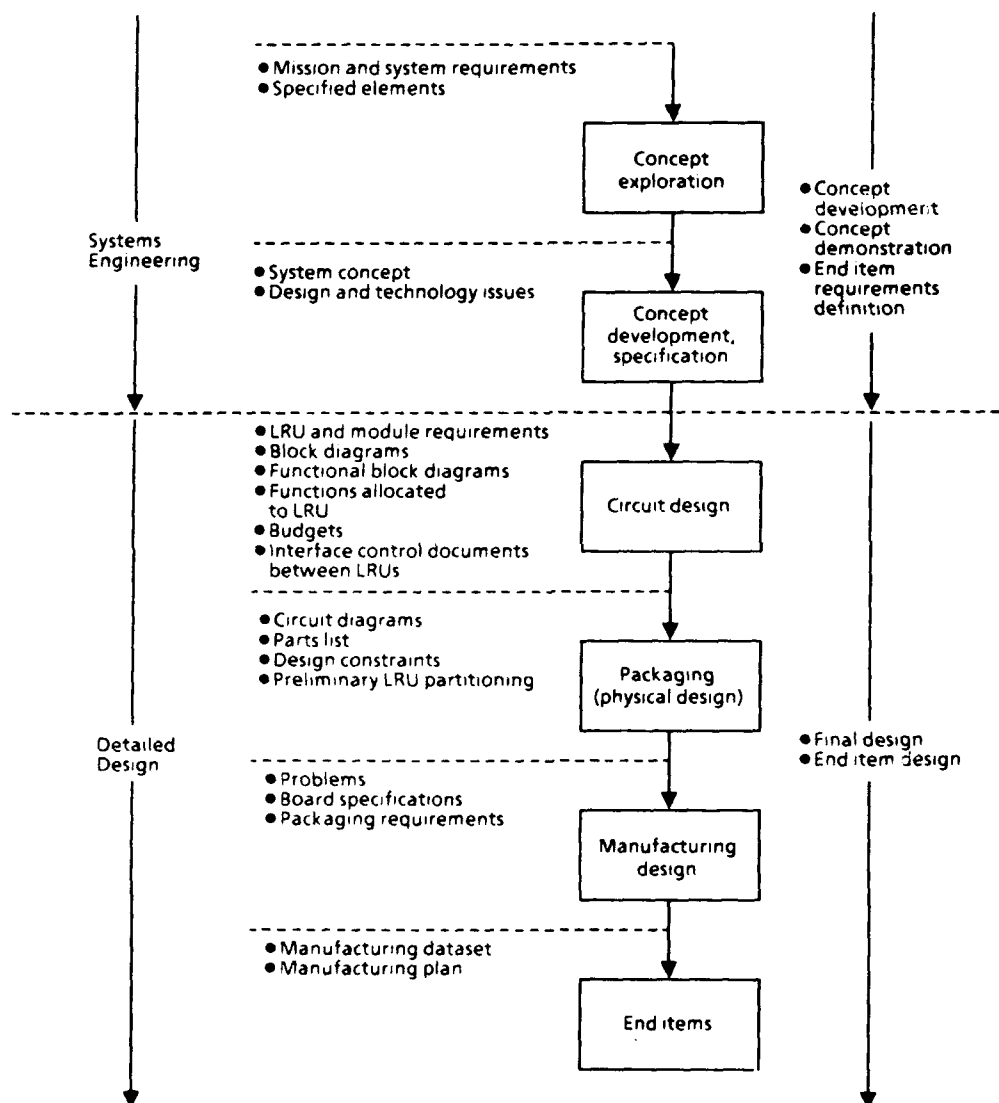


Figure 2. Basic Design Process

The design process usually begins with a statement of need and a set of proposed requirements and constraints specified by the customer. Requirements are typically defined or proposed for system performance, acquisition cost, availability, and maintainability. Occasionally additional

requirements or design constraints such as those shown in Figure 3 are also imposed or evolve through negotiations between the DOD customer and the contractor.

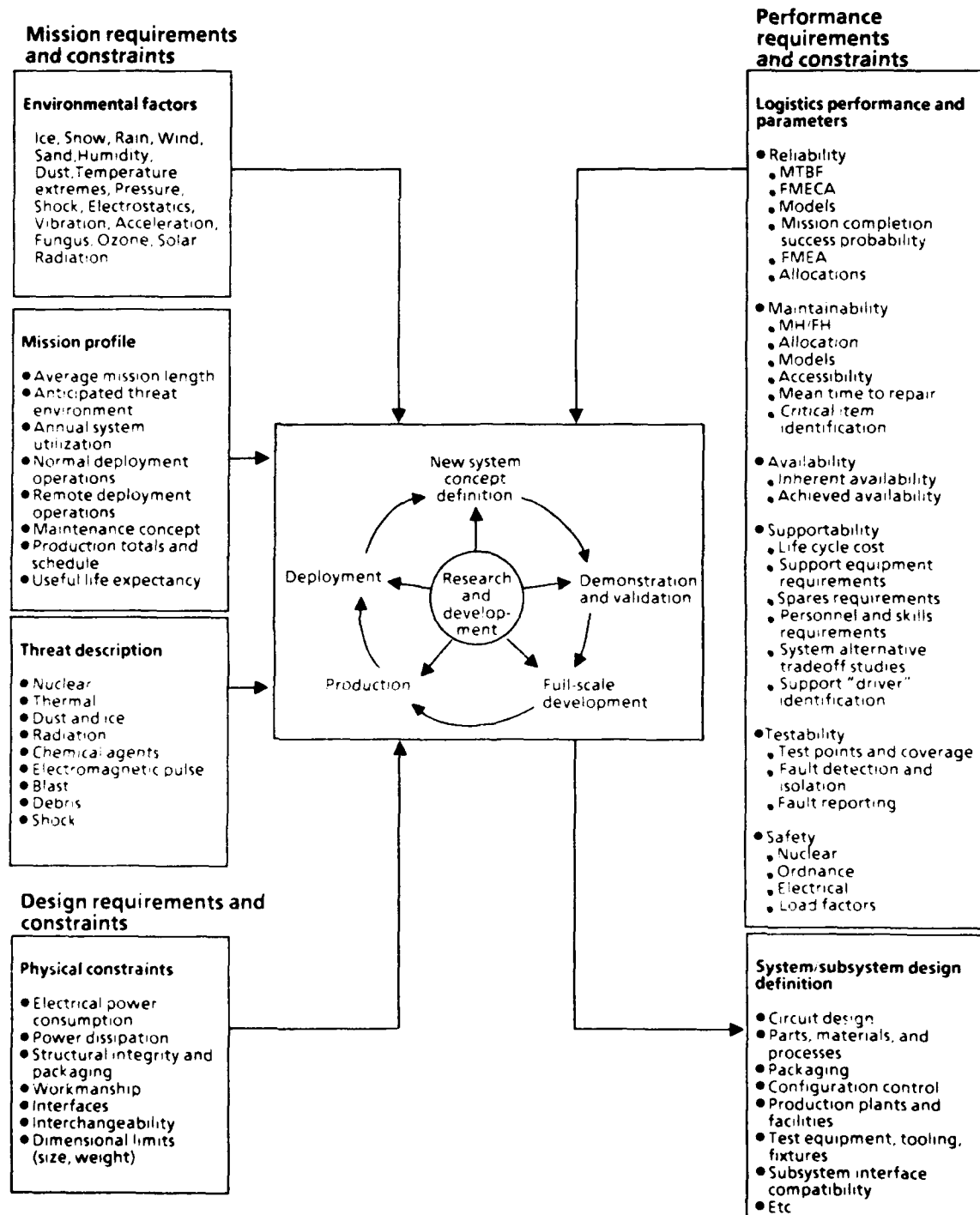


Figure 3. Design Requirements.

Although it is common for the requirements defined by the customer to be inconsistent and/or incomplete, a number of factors limit the degree to which the contractor is able to resolve any issues with the DOD. Among these are the following:

1. Competitive pressures. Once one contractor accepts the requirements, others competing for the award must also do so to ensure that they remain in contention.
2. Restrictions in the procurement process. In competitive bid situations, interaction between the contractor and the DOD customer is restricted to a large degree.
3. Without designing the system it is difficult to define requirements that are complete, consistent, and achievable.

Normally a small group of experienced system designers is formed early in the systems engineering phase to begin developing a set of system functional requirements satisfying the mission needs. This group uses the experience of its members and draws on a variety of specialists to develop a system concept meeting all the requirements specified by the customer. Depending upon program variables (e.g., budget, whether a concept is proposed by the customer), the group may develop and document several alternative concepts that are then reviewed and compared by various supporting organizations.

Once a baseline system concept has been agreed to by all participating parties, requirements are defined for end items about the size of an LRU. With the help of specialists from several design disciplines, these requirements are derived from the overall system requirements by an iterative application of the basic system engineering process.

Once a relatively well defined set of requirements for an end item is developed, the detailed design of the item begins.

## **2.3 RESPONSIBILITIES AND ROLES**

Within Boeing and most other aerospace companies, responsibility for the design is often shared among several organizations. The usual organizations sharing responsibility are described in the following sections.

### **2.3.1 Systems Engineering**

Systems Engineering is responsible for developing a system design concept that meets the needs of the customer. Until the detailed design effort begins (Section 4.0), Systems Engineering orchestrates the involvement of the other design specialties to develop an overall system concept and to resolve any technical issues associated with this concept. It is the responsibility of this organization to ensure that the system-level and end-item specifications are consistent and meet the appropriate system requirements defined by the customer.

Table 1 shows the design-related tasks performed by Systems Engineering during each of the phases in the DOD acquisition life cycle. Figure 4 shows the interaction between Systems Engineering and major design functions.



**TABLE 1. Design Activities by Phase-Systems Engineering**

Concept exploration	Concept demonstration and validation	Full-scale development	Production
<ul style="list-style-type: none"> <li>● Prepare system specification and external system interface definitions</li> </ul>	<ul style="list-style-type: none"> <li>● Prepare system/segment specification and system/segment interface control documents</li> </ul>	<ul style="list-style-type: none"> <li>● Prepare configuration item specification and hardware and software interface control documents</li> </ul>	
<ul style="list-style-type: none"> <li>● System requirements analysis                             <ul style="list-style-type: none"> <li>- Completeness</li> <li>- Understanding</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● System/segment requirements analysis                             <ul style="list-style-type: none"> <li>- Completeness</li> <li>- Achievability</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● LRU requirements analysis                             <ul style="list-style-type: none"> <li>- Completeness</li> <li>- Achievability</li> </ul> </li> </ul>	
<ul style="list-style-type: none"> <li>● System functional analysis</li> </ul>	<ul style="list-style-type: none"> <li>● System/segment functional analysis</li> </ul>	<ul style="list-style-type: none"> <li>● LRU functional analysis</li> </ul>	
<ul style="list-style-type: none"> <li>● System requirements allocation                             <ul style="list-style-type: none"> <li>- Derive requirements</li> <li>- Define interfaces</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● System/segment requirements allocation                             <ul style="list-style-type: none"> <li>- Derive requirements</li> <li>- Define interfaces</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● LRU requirements allocation                             <ul style="list-style-type: none"> <li>- Derive requirements</li> <li>- Define interfaces</li> </ul> </li> </ul>	
<ul style="list-style-type: none"> <li>● System alternatives generation                             <ul style="list-style-type: none"> <li>- Brainstorm</li> <li>- Comparable systems</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● System/segment alternatives generation                             <ul style="list-style-type: none"> <li>- Brainstorm</li> <li>- Comparable designs</li> <li>- Existing solutions</li> <li>- Failure modes analysis</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● LRU alternatives generation                             <ul style="list-style-type: none"> <li>- Comparable designs</li> <li>- Existing solutions</li> <li>- Failure modes analysis</li> </ul> </li> </ul>	
<ul style="list-style-type: none"> <li>● System trade studies                             <ul style="list-style-type: none"> <li>- Estimated performance</li> <li>- Estimated production time</li> <li>- Estimated design risk</li> <li>- Estimated life cycle cost</li> <li>- Estimated size and complexity</li> <li>- Estimated power and cooling</li> <li>- Estimated weight</li> <li>- Estimated reliability</li> <li>- Estimated maintainability</li> <li>- More detailed design of high-risk portions</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● System/segment trade studies                             <ul style="list-style-type: none"> <li>- Estimated performance</li> <li>- Estimated functionality</li> <li>- Breadboard studies</li> <li>- Estimated design time</li> <li>- Estimated production time</li> <li>- Estimated design risk</li> <li>- Estimated life cycle cost</li> <li>- Estimated size and complexity</li> <li>- Estimated power and cooling</li> <li>- Estimated weight</li> <li>- Estimated technology availability</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● LRU trade studies                             <ul style="list-style-type: none"> <li>- Performance estimates</li> <li>- Functionality analysis</li> <li>- Breadboard studies</li> <li>- Schedule estimates</li> <li>- Design risk estimates</li> <li>- Size and weight estimates</li> <li>- Design complexity</li> <li>- Power and cooling estimates</li> <li>- Reliability analysis</li> <li>- Maintainability analysis</li> <li>- Supportability analysis</li> <li>- Life cycle cost analysis</li> <li>- Technology availability studies</li> </ul> </li> </ul>	
<ul style="list-style-type: none"> <li>● System design synthesis</li> </ul>	<ul style="list-style-type: none"> <li>● System/segment design synthesis</li> </ul>	<ul style="list-style-type: none"> <li>● LRU design synthesis</li> </ul>	
<ul style="list-style-type: none"> <li>● System design evaluation                             <ul style="list-style-type: none"> <li>- Requirements comparison</li> <li>- Performance estimation</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● System/segment design evaluation                             <ul style="list-style-type: none"> <li>- Requirements comparison</li> <li>- Performance estimation</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● LRU design evaluation                             <ul style="list-style-type: none"> <li>- Requirements comparison</li> <li>- Performance analysis</li> </ul> </li> </ul>	

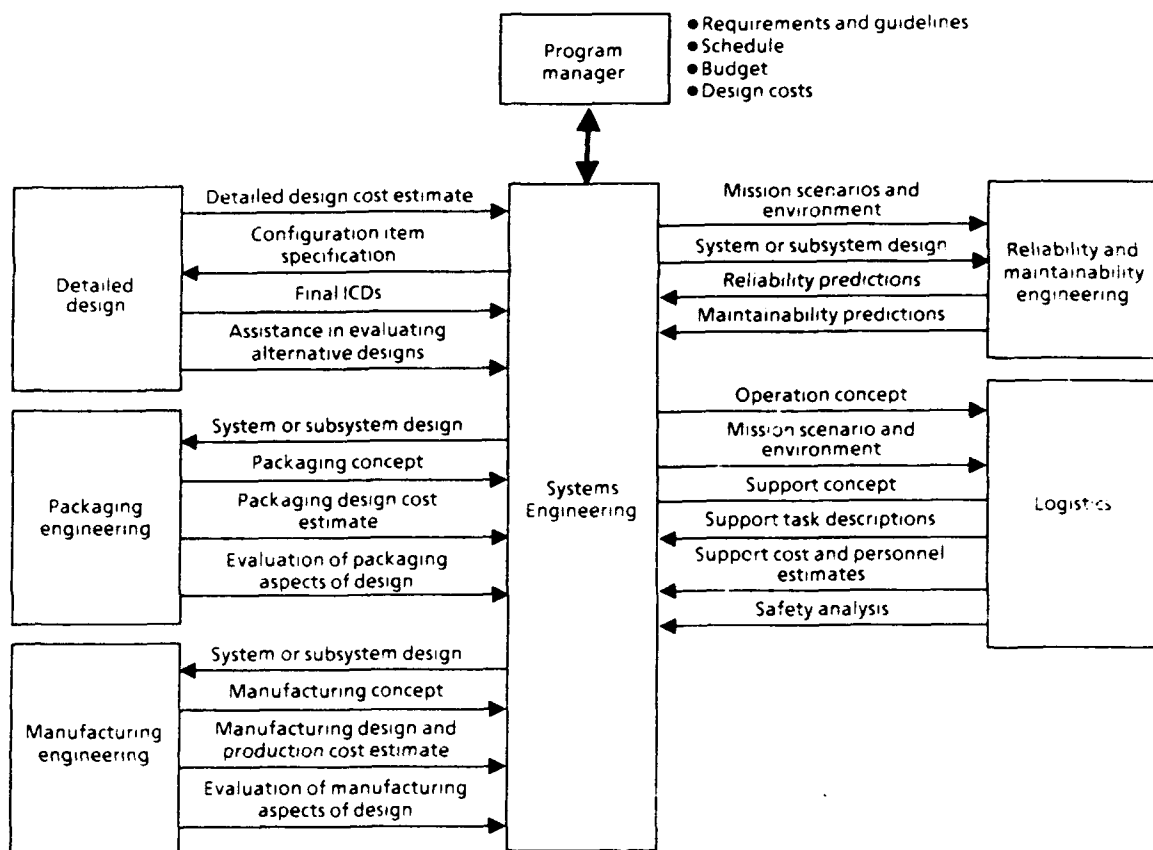


Figure 4. Systems Engineering Functional Interfaces

### 2.3.2 Circuit Design

The primary role of Design Engineering (circuit design) is to complete the detailed design of the end item's electronics. During the initial phases of the design process, this organization assists Systems Engineering in developing a feasible system concept and derives requirements and specifications for the end items based upon this concept.

Table 2 shows the design-related tasks performed by Design Engineering during each of the phases in the DOD acquisition life cycle. Figure 5 shows the information interchange between Design Engineering and the other major design functions.

**TABLE 2. Design Activities by Phase—Circuit Design**

Concept exploration	Concept demonstration and validation	Full-scale development	Production
<ul style="list-style-type: none"> <li>● Assist Systems Engineering</li> <li>● Concepts</li> <li>● Requirements analysis</li> <li>● Trades</li> </ul>	<ul style="list-style-type: none"> <li>● Assist Systems Engineering</li> <li>● Requirements analysis</li> <li>● Functional analysis</li> <li>● Function allocation</li> <li>● Alternatives</li> <li>● Trades</li> <li>● Requirements allocation</li> <li>● Interface definition</li> </ul>	<ul style="list-style-type: none"> <li>● Detailed circuit design               <ul style="list-style-type: none"> <li>● Functional analysis</li> <li>● Functional allocation</li> <li>● Interface definition</li> <li>● Alternatives generation and analysis</li> <li>● Trade studies</li> <li>● Subfunction analysis</li> <li>● Subfunction interface definition</li> <li>● Circuit alternatives</li> <li>● Circuit trades</li> <li>● Circuit design</li> <li>● Evaluation                   <ul style="list-style-type: none"> <li>– Breadboard</li> <li>– Schematic capture</li> <li>– Test procedures</li> <li>– Functional verification</li> <li>– Nominal timing</li> <li>– Critical path analysis</li> <li>– Worst case timing</li> <li>– Loading analysis</li> <li>– Electrical stress</li> <li>– Preliminary layout</li> <li>– Fault detection</li> <li>– Fault isolation</li> <li>– False alarms</li> <li>– Testability</li> </ul> </li> </ul> </li> <li>● Evaluate and incorporate recommended changes</li> </ul>	

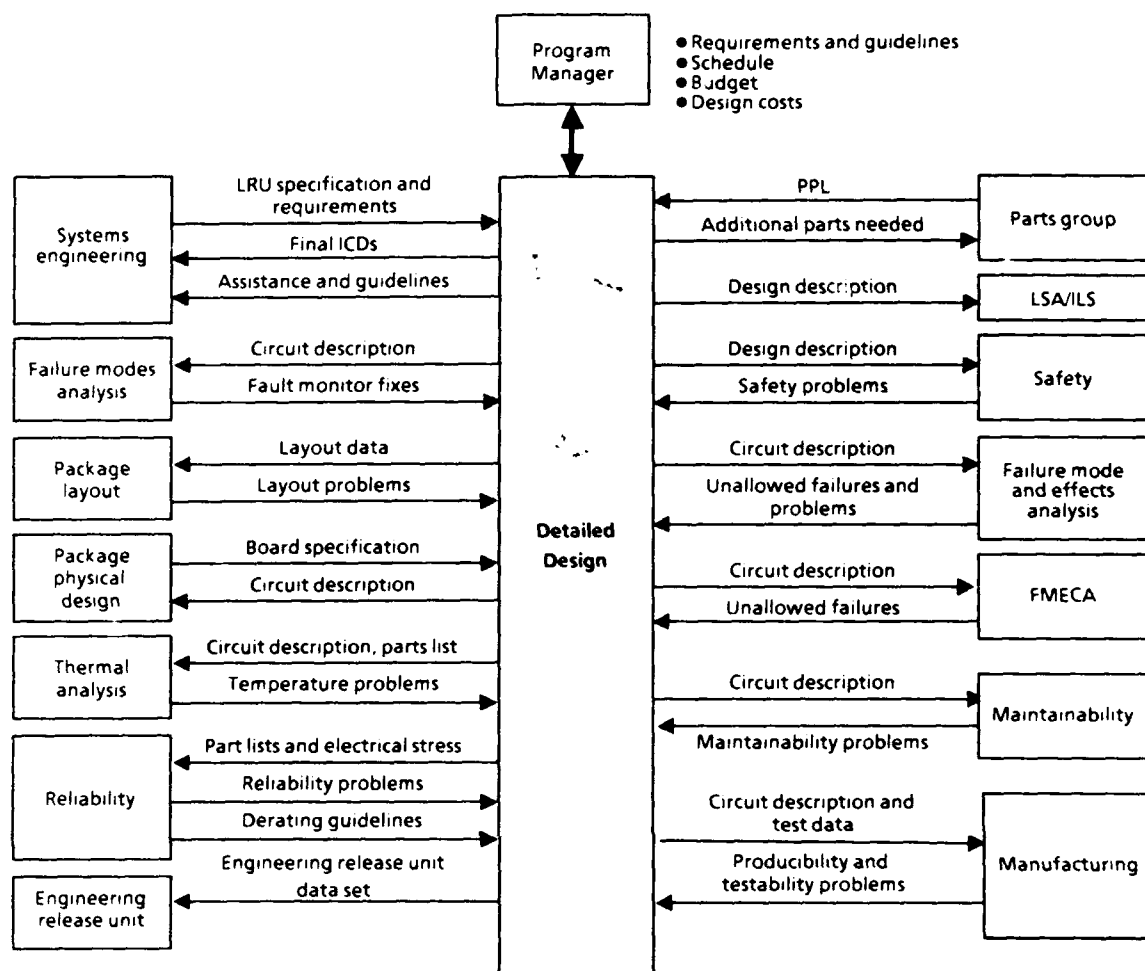


Figure 5. Detailed Design Functional Interfaces

### 2.3.3 Design Assurance

Design Assurance's role during the design process is to ensure that certain airworthiness and operational criteria are satisfied. Typically, this involves assessing the reliability, safety, and fault-monitoring capabilities of the system concept and the end-item designs and the methods they provide for maintaining and verifying the operational readiness of the system. During the initial phases of the design process, this organization helps Systems Engineering develop a feasible system concept and derive requirements and specifications for the end items.

Table 3 shows the design-related tasks performed by Design Assurance during each of the phases in the DOD acquisition life cycle. Figure 6 shows the information interchange between Design Assurance and the major design functions.

**TABLE 3. Design Activities by Phase—Design Assurance and Logistics Support**

Standard for compliance	Phase			
	Concept exploration	Concept demonstration and validation	Full-scale development	Production
<ul style="list-style-type: none"> <li>● Reliability MIL-STD-785B</li> </ul>	<ul style="list-style-type: none"> <li>● Modeling (201)</li> </ul>	<ul style="list-style-type: none"> <li>● Allocations (202)</li> <li>● Failure mode analysis</li> </ul>	<ul style="list-style-type: none"> <li>● Predictions (203)</li> <li>● Parts program (207)</li> <li>● FMEA and FMECA (204)</li> <li>● Failure modes analysis</li> <li>● Reliability critical items (208)                             <ul style="list-style-type: none"> <li>● Sneak circuit analysis (205)</li> </ul> </li> <li>● Tolerance analysis (206)</li> </ul>	<ul style="list-style-type: none"> <li>● Quality test</li> <li>● Burn-in</li> </ul>
<ul style="list-style-type: none"> <li>● Maintainability MIL-STD-470</li> </ul>	<ul style="list-style-type: none"> <li>● Modeling (201)</li> </ul>	<ul style="list-style-type: none"> <li>● Allocations (202)</li> </ul>	<ul style="list-style-type: none"> <li>● Predictions (203)</li> <li>● FMEA-M (204)</li> <li>● Maintainability design criteria (205)</li> </ul>	<ul style="list-style-type: none"> <li>● Maintainability analysis (207)</li> </ul>
<ul style="list-style-type: none"> <li>● Supportability MIL-STD-1388-1A</li> </ul>	<ul style="list-style-type: none"> <li>● Use study (201)</li> </ul>	<ul style="list-style-type: none"> <li>● Use study (201)</li> <li>● Logistics study analysis strategy (101)</li> <li>● Logistics study analysis plan (102)</li> <li>● Mission hardware and software standardization (202)</li> <li>● Comparison analysis (203)</li> <li>● Technical opportunity (204)</li> <li>● Support factors (205)</li> <li>● Functional requirements identification (301)</li> <li>● Support analysis alternatives (302)</li> <li>● Alternative and tradeoff analysis (303)</li> </ul>	<ul style="list-style-type: none"> <li>● Task analysis (401)</li> <li>● Early fielding analysis (402)</li> </ul>	

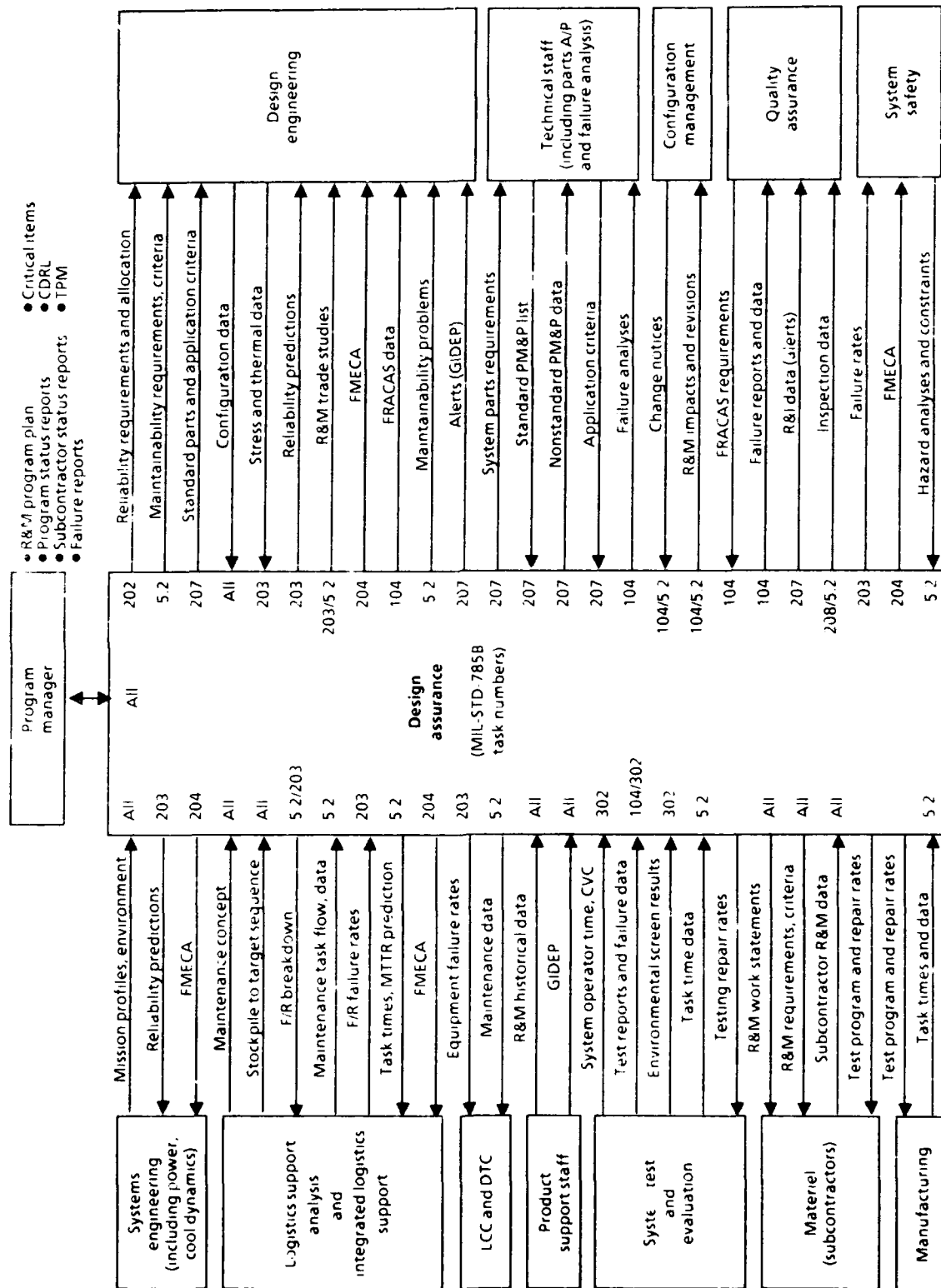


Figure 6. Design Assurance Functional Interfaces

#### **2.3.4 Packaging Design**

Packaging Engineering is responsible for the physical design of the LRU. During the initial phases of the design process, Packaging Engineering helps Systems Engineering develop a feasible system concept and derive requirements and specifications for the end items.

Table 4 shows the design-related tasks performed by the Packaging Engineering organization during each of the phases in the DOD acquisition life cycle. Figure 7 shows the interaction of this group with the major design functions.

#### **2.3.5 Manufacturing Design**

Manufacturing fabricates the physical design. Its concern during the design process is the producibility and cost of the design. Manufacturing Engineering develops manufacturing and quality assurance plans from the electronic and physical descriptions of the design developed by Design Engineering and Packaging Engineering. During the initial phases of the design process, Manufacturing Engineering assists Systems Engineering in developing a feasible system concept and deriving requirements and specifications for the end items.

Table 4 shows the design-related tasks performed by this organization during each of the phases in the DOD acquisition life cycle. Figure 8 shows the interaction of Manufacturing Engineering with the other major design functions.

#### **2.3.6 Logistics Support**

The primary role of Logistics Support during the design process is to assess the life-cycle support requirements and costs of the system concept and the end-item designs. Logistics Support is also responsible for the preparation of customer support material such as maintenance and operations manuals. During the initial phases of the design process, Logistics Support helps Systems Engineering develop a feasible system concept and derive requirements and specifications for the end items. The primary difference between Logistics Support and Design Assurance is that Design Assurance is concerned with operational readiness and airworthiness issues, while Logistics Support concentrates on the support-related requirements of the system.

Table 3 shows the design-related tasks performed by the Logistics Support organization during each of the phases in the DOD acquisition life cycle. Figure 6 shows the interaction of this group with the other major design functions.

**TABLE 4. Design Activities by Phase—Packaging and Manufacturing**

Concept exploration	Concept demonstration and validation	Full-scale development	Production
<ul style="list-style-type: none"> <li>● Support Systems Engineering in concept development</li> <li>● Rough approximations of— <ul style="list-style-type: none"> <li>● System <ul style="list-style-type: none"> <li>– Size</li> <li>– Weight</li> <li>– Hardware</li> <li>– Interfaces</li> <li>– Power requirements</li> </ul> </li> <li>● Line-replaceable unit <ul style="list-style-type: none"> <li>– Size</li> <li>– Weight</li> <li>– Hardware</li> <li>– Interfaces</li> <li>– Partitioning</li> <li>– Power requirements</li> </ul> </li> <li>● Boards <ul style="list-style-type: none"> <li>– Size</li> <li>– Weight</li> <li>– Number of boards</li> <li>– Hardware</li> <li>– Connector input/output</li> <li>– Component placements</li> <li>– Power requirements</li> <li>– Critical circuit</li> <li>– Design constraints</li> </ul> </li> <li>● Nuclear hardness and survivability requirements</li> <li>● Generic parts</li> <li>● Stress and vibration requirements</li> <li>● Thermal requirement</li> <li>● Read-only memory packaging design costs</li> <li>● Schedule</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● Support Systems Engineering in concept development</li> <li>● Estimate and define: <ul style="list-style-type: none"> <li>● System <ul style="list-style-type: none"> <li>– Size</li> <li>– Weight</li> <li>– Hardware</li> <li>– Interfaces</li> <li>– Power requirements</li> </ul> </li> <li>● Line-replaceable unit <ul style="list-style-type: none"> <li>– Size</li> <li>– Weight</li> <li>– Hardware</li> <li>– Interfaces</li> <li>– Partitioning</li> <li>– Power requirements</li> </ul> </li> <li>● Boards <ul style="list-style-type: none"> <li>– Size</li> <li>– Weight</li> <li>– Number of boards</li> <li>– Hardware</li> <li>– Connector input/output</li> <li>– Component placements</li> <li>– Power requirements</li> <li>– Critical circuit</li> <li>– Design constraints</li> </ul> </li> <li>● Nuclear hardness and survivability requirements</li> <li>● Generic parts</li> <li>● Stress and vibration requirements</li> <li>● Thermal requirement</li> <li>● Firm packaging engineering costs</li> <li>● Schedule</li> </ul> </li> <li>● Perform preliminary package analysis: <ul style="list-style-type: none"> <li>● Thermal</li> <li>● Stress and vibration</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● Support Design Engineering in line-replaceable unit and board layout and breadboard design</li> <li>● Define and specify— <ul style="list-style-type: none"> <li>● System <ul style="list-style-type: none"> <li>– Size</li> <li>– Weight</li> <li>– Hardware</li> <li>– Interfaces</li> <li>– Power requirements</li> </ul> </li> <li>● Line-replaceable unit <ul style="list-style-type: none"> <li>– Size</li> <li>– Weight</li> <li>– Hardware</li> <li>– Interfaces</li> <li>– Partitioning</li> <li>– Power requirements</li> </ul> </li> <li>● Boards <ul style="list-style-type: none"> <li>– Size</li> <li>– Weight</li> <li>– Number of boards</li> <li>– Hardware</li> <li>– Connector input/output</li> <li>– Component placements</li> <li>– Power requirements</li> <li>– Critical circuit</li> <li>– Design constraints</li> </ul> </li> <li>● Nuclear hardness and survivability requirements</li> <li>● Detail part numbers</li> <li>● Generic parts</li> <li>● Stress and vibration characteristics</li> <li>● Thermal characteristics</li> <li>● Schedules</li> </ul> </li> <li>● Design <ul style="list-style-type: none"> <li>● System <ul style="list-style-type: none"> <li>– Envelope</li> <li>– Cabling</li> <li>– Cooling</li> <li>– Hardware</li> </ul> </li> <li>● Line-replaceable unit <ul style="list-style-type: none"> <li>– Envelope</li> <li>– Cabling</li> <li>– Cooling</li> <li>– Hardware</li> </ul> </li> <li>● Board <ul style="list-style-type: none"> <li>– Component placement</li> <li>– Route board components</li> <li>– Generate board fabrication data</li> <li>– Generate numerical control data</li> <li>– Generate drawings</li> </ul> </li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>● Incorporate post-full-scale development changes into production packaging design</li> </ul>



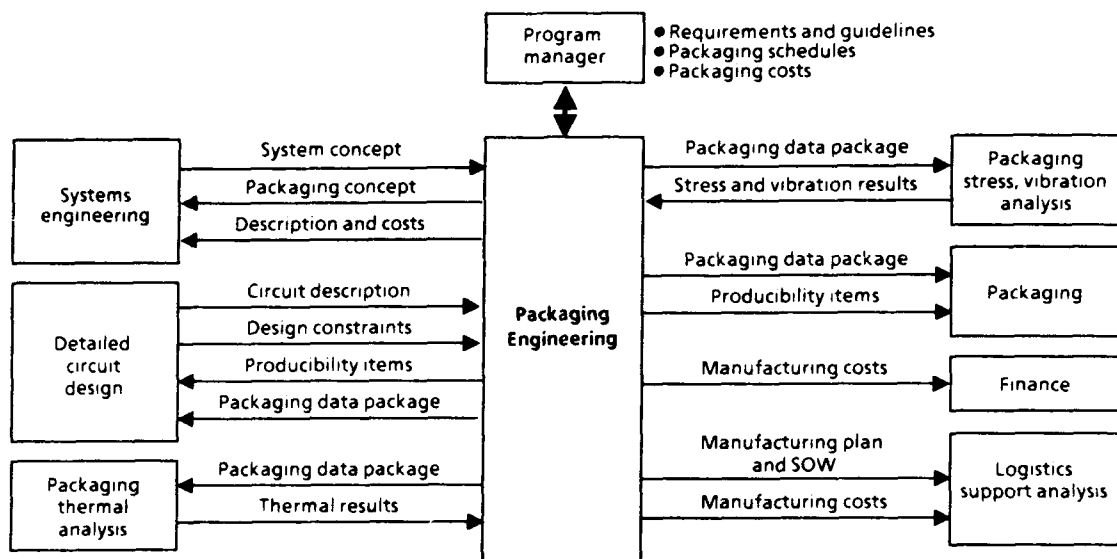


Figure 7. Packaging Engineering

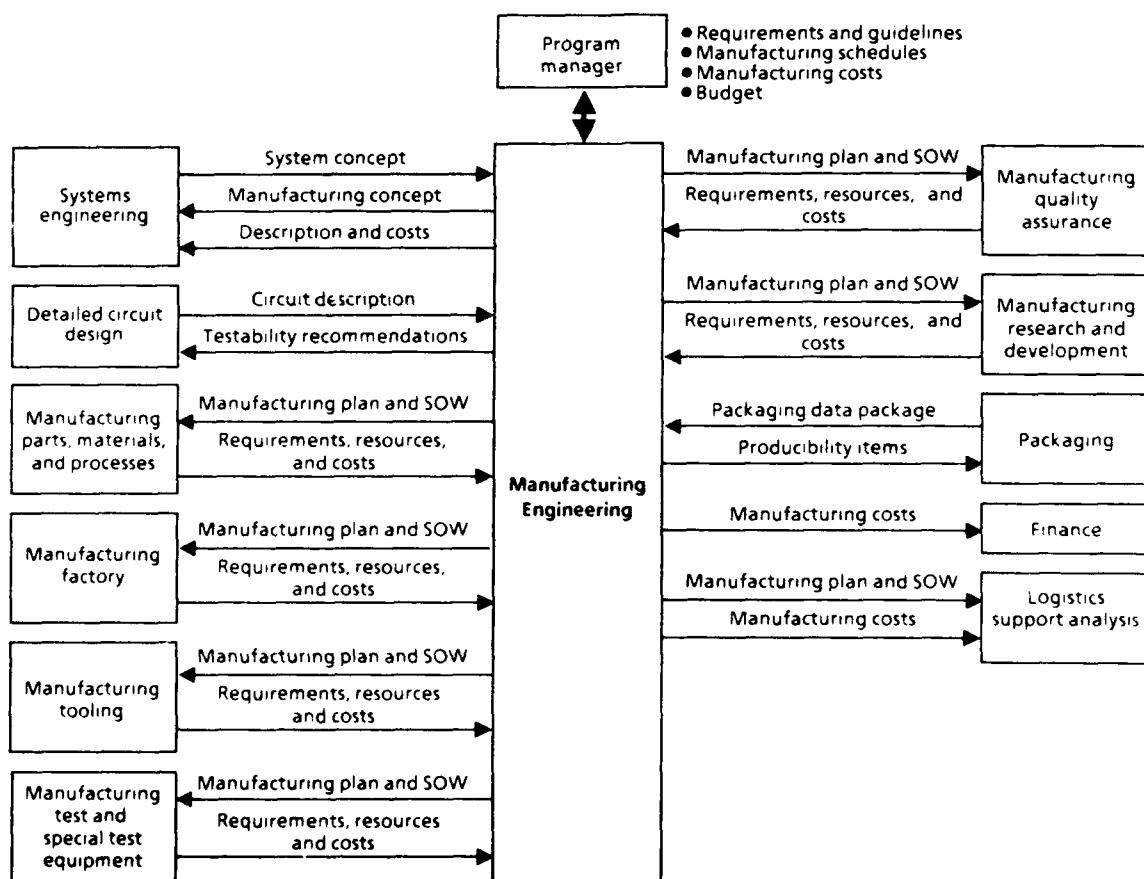


Figure 8. Manufacturing Engineering

### **3.0 SYSTEMS ENGINEERING PHASE**

The systems engineering phase covers requirements definition to full-scale development (FSD). The main purpose of the systems engineering phase is to produce specifications containing detailed requirements and functional block diagrams for a system satisfying the customer's needs. This specification is refined to a level of definition that can provide the basis for detailed design of the system components. A major consideration during this phase is risk reduction. There should be high confidence that the specified system will meet the requirements and can be designed and produced on schedule and within budget.

#### **3.1 OVERVIEW: INITIAL REQUIREMENTS TO LINE REPLACEABLE UNIT DESIGN**

The systems engineering function is repeated at a series of levels of increasing design detail. At each level, systems engineering is a process of analyzing requirements, proposing solutions, analyzing the proposed solutions to determine their relative merit, and synthesizing or selecting a single solution (Figure 9). This cycle occurs repeatedly until the specifications are sufficiently detailed to serve as input to the detailed design process. The success of the effort will depend on the completeness and accuracy of understanding of the requirements, the degree to which the set of proposed solutions covers the design space, the validity of the analysis of these solutions, and the degree to which the evaluation criteria reflect the customer's priorities.

Consider the task of developing a system for storing and launching small, mobile intercontinental ballistic missiles (ICBM). Among the issues considered in the first systems engineering phase would be the nature of the transporter, the type of storage facilities required, the means of launching from the transporter, and the control facilities for the overall process. Possibilities for the nature of the transporter might include a rail vehicle, a vehicle on tracks, or a vehicle on pneumatic tires. Each of these could be designed to travel between alternative storage sites in tunnels or on the surface. After detailed studies of alternatives of this nature, the designers might settle on a certain size and weight of missile, a surface vehicle running on pneumatic tires, and a control concept based on a fiber-optic network. Specifications would be prepared for each of these elements, with particular attention to the interfaces between elements. The decisions made in the first series of design studies give rise to derived requirements that would be included in these specifications. These specifications would be sufficiently detailed that if a subsystem were developed to meet each set of specifications, the subsystems would combine to provide a small, mobile ICBM reflecting the design decisions made during the first phase. At this point, the same process could be carried out independently on each of these three systems.

In this process, alternative concepts are considered in sufficient detail to enable the engineers to choose among them confidently. One alternative is selected and explored in greater detail to confirm that it can be produced in the time and for the money available and that it will perform as intended. This alternative is then documented in a series of specifications for the components of the system.

Our interest in this section is to document the types of studies that contribute to this process, including the data the studies are based on and the nature and significance of their results. We will concentrate on the design of an avionics subsystem, although we will give some consideration to the design studies of the system containing the avionics, since these studies are the source of many of the derived requirements levied on the avionics subsystem.

#### **3.2 THE SYSTEM LEVEL**

Traditionally, a small group of experienced system designers has been responsible for the system-level design. It is becoming more common to form a team of varied experience and background, including systems engineers, hardware and software engineers, manufacturing engineers, logistics engineers, life cycle cost analysis experts, and experts in other areas of particular importance to the

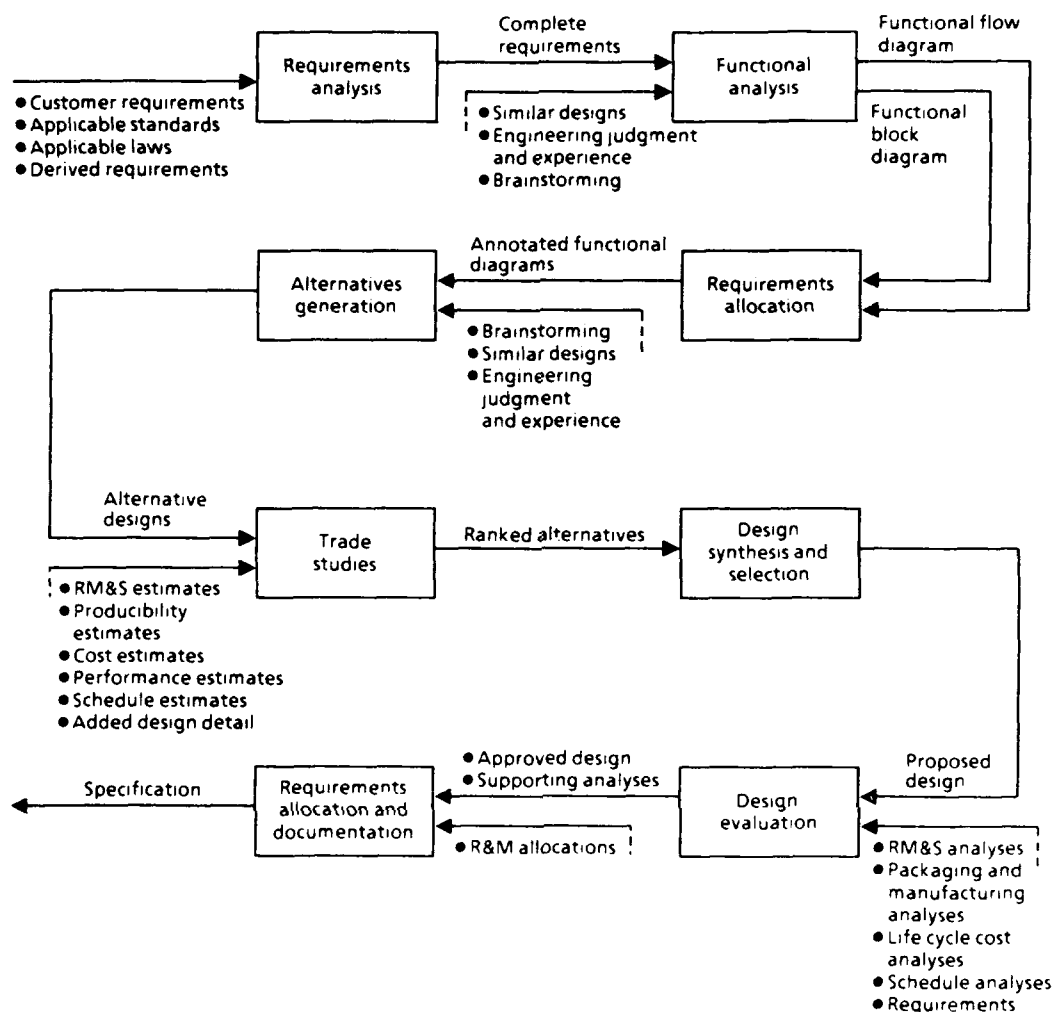


Figure 9. Systems Engineering Process

design under consideration. It is often assumed that the goal of systems engineering is to determine the system concept that best meets the customer's needs. In practice, because of considerations of schedule, budget, and risk aversion, the actual goal is the least expensive, least risky concept that adequately satisfies the customer's needs. This actual goal serves the interests of the designer, who has limited time and money to develop a solution to the problem, and of the customer, who must pay for the design and usually has a current need for the product of the design. Thus, the majority of design at all levels is modifying and combining existing designs to meet a new goal. Novelty is high risk and potentially high cost and is avoided when possible. Such novelty as is included is usually a concept that has been refined and tested in research and development efforts so the risk is reduced to acceptable levels.

At the system level, the design engineers select a system concept and document it in a series of system segment specifications. There are four main activities at the system level. Mission requirements analysis confirms that the designer and the customer agree in their understanding of the customer needs and translates these needs into a complete set of mission requirements. In functional analysis

and requirements allocation, the system to be designed is described as a set of actions and capabilities, and the requirements are allocated among these functions. A variety of functional decompositions is considered, and trade studies are performed to provide a basis for synthesizing the best design from elements of the alternatives considered. This chosen design concept is documented in the system segment specifications.

The following sections describe these activities in more detail.

### **3.2.1 Mission Requirements Analysis**

The initial system requirements may be quite vague ("design a small, mobile ICBM system" or "design a replacement for the B-52"). These requirements are usually accompanied by a definition of a mission the new system is to perform. The specified customer needs may also include performance criteria, interfaces to other systems, cost and schedule constraints, and operational and support requirements. In addition to the specified requirements, there may be many implicit requirements imposed on the system that must be identified. These include general customer standards applicable to all systems; customer standards applying to this particular system because of its size, operational environment (e.g., a nuclear-war zone), its mission, etc.; requirements arising from various public laws; and requirements contained in the contractor's standards and policies.

The systems engineering process begins by determining the implicit requirements and studying the requirements and mission definition to determine if the mission definition is complete and if the specified requirements correspond to the mission. The engineer depends on experience and engineering judgment in carrying out this process and elicits the opinions of other engineers experienced in the area of the design to increase the likelihood that the analysis is thorough and accurate. The requirements are expressed quantitatively, and a method is specified for evaluating a candidate design with respect to each requirement.

The expressed needs will usually leave large areas unspecified. The engineer must identify those areas and help the customer determine suitable requirements, frequently by proposing possibilities for the customer to choose among. Where there is a range of possibilities acceptable to the customer, this fact must be documented so the remaining design work will not be unnecessarily constrained. An important task at this level is to distinguish negotiable requirements from those that must be met. This distinction can be important later in the design process, when requirements may conflict and the designer must decide which requirements to meet and which to relax.

### **3.2.2 Functional Decomposition and Requirements Allocation**

The first step in determining a concept for a system that satisfies the mission requirements is to prepare a functional flow diagram. This diagram answers the question "What has to happen?" The blocks in this diagram correspond to system requirements. The next step of the process is preparation of a functional block diagram. The functional block diagram answers the question "How can the events of the functional flow diagram be made to happen?" The boxes in this diagram correspond to design entities. In reality, these design processes occur in parallel. As functional flows are considered, some thought must be given to how to produce them in order to keep the flows realistic. As these ideas of functional blocks are pursued, they may lead the designer to recognize additional flows that are required.

Several alternative functional flows may be considered, and for each of them, several functional block diagrams may be prepared. There is no formal technique for ensuring that these alternatives are in any way complete. They are based on customer requests, comparisons with designs of similar systems, and the experience and ability of the design engineers. To increase the probability that the functional decompositions are complete and the most important alternatives are being considered, the designers may call on other engineers with particular experience in some aspect of the system

being developed. Brainstorming techniques are used to further expand the range of alternatives considered.

Once a functional flow diagram and a functional block diagram are produced, the requirements are allocated to the functional blocks. This allocation has several roles. It helps ensure that the design under consideration actually meets all of the requirements levied on the system. It provides traceability in both directions, identifying the functional blocks that satisfy a particular requirement and the requirements that constrain the design of each functional block. It also establishes more detailed requirements for the functional blocks. The intent is to provide a set of requirements for a system of functional blocks so that the blocks can be developed in parallel; if each block meets its requirements, the blocks will combine to form a system that meets the system requirements.

As the design and operational concepts evolve, experts prepare supporting concepts such as a system maintenance concept, a manufacturing concept, a support system concept, and a system test concept. In the team approach to design, these experts are often part of the design team. Otherwise, it is left to the discretion of the design engineer to determine when expert advice is required and what expert should be called on to provide it.

### **3.2.3 Trade Studies**

Once a set of alternative functional flows and functional block diagrams has been developed, trade studies are used to make choices among them. Trade studies are also used to determine the sensitivity of a proposed design to variations in the requirements and to resolve other technical, cost, or schedule issues. The decision to perform a trade study is based on the perceived risk associated with a decision. If the potential impact is small, a choice is made without the cost of a formal study. If the risk is very great, the design may be carried to a detailed level in order to improve confidence in the results of the study.

The data for the trade studies are prepared by specialist engineers in the relevant areas. Until now, it has been up to the design engineer to decide when a trade study is warranted and if any specialized help was needed, and to seek out that help. With the newer approach using a team of varied specialties, there is usually expert opinion available to determine whether a trade study is needed and to provide the necessary data when one is required.

Before the trade studies are begun, a baseline design concept is specified. This baseline is continually updated as new choices are made on the basis of ongoing analysis. Trade studies are performed on many elements of the design, and these elements interact. To avoid a combinatorial explosion in the comparisons required in trade studies, when one element of the design is being considered all other elements are usually assumed to have their baseline configuration.

Trade studies depend on estimates of cost, weight, reliability, and other parameters. For instance, Manufacturing estimates the production cost of each design and identifies those aspects of a design that contribute disproportionately to this cost. Similarly, Logistics Support estimates support costs and other downstream costs that may be necessary for life cycle cost estimation. The estimates for a proposed design are based on the performance of an existing design of similar capability. The engineers draw on personal experience and on extensive databases of historical data to identify these similar existing designs and to determine the observed values of the parameters of interest. Since the design is not well defined at this point, there is a large margin of uncertainty in these estimates.

Generally the expressed customer requirements determine how much weight is given in the trade studies to each parameter (e.g., life-cycle cost, production cost, performance, and reliability). Estimates of parameters that do not drive the design are important chiefly to identify unexpected areas of risk (e.g., significant impacts on cost, schedule, performance, or reliability).

**Failure Modes Analysis.** A standard input to trade studies is a failure modes analysis (FMA). In this analysis, the effect on system operability of each possible failure of each functional block in each system operating mode is determined. The functional block diagram used in this analysis must include the current provisions for operational status monitoring and fault detection. A related analysis included in the FMA is an interface analysis, in which the effects of failures in the various interfaces between functional blocks are determined.

FMA has two objectives:

1. To ensure that the fault detection and fault isolation (FD/FI) provisions of the design are adequate to meet the FD/FI requirements of the contract.
2. To support development of effective system maintenance instructions by identifying each potential hardware failure and determining the indications that will be available to the system operators and maintenance personnel.

The results of the FMA are documented in the failure mode management concept document, which is updated as design choices are made and design detail is increased.

**Reliability, Maintainability, and Supportability Involvement.** Reliability engineers prepare estimates of the mean time between failure (MTBF) and mission completion success probability (MCSP) for each alternative. The MCSP is the probability that the mission objectives, including safe return, will be achieved. Estimating MCSP requires an explicit mission scenario telling how long the mission will last, during what portion of the mission a particular capability will be used, and what minimum functionality must be maintained for the mission to succeed. Within this scenario, the effect of the failure of each functional block on MCSP can be determined.

The likelihood of failure is estimated for each functional block. These estimates are based on MTBF values for similar hardware, with corrections for differences between the hardware and for differences in operating environment. The reliability engineer draws on databases of hardware experience to find historical MTBF values, relying on experience to make the most appropriate use of the historical data. Adjustments for differences in hardware and environment are based on a combination of experience and standard derating models. If there is an overall reliability requirement on the design, these estimates are compared with that requirement. If the estimated reliability does not meet the requirement, the reliability engineer can propose redundancy at critical points in the design and prepare reliability estimates for the modified design. The final estimates of reliability for each alternative are included in the reliability mathematical model report. This report also includes a description of the model used to derive the estimates and the justification for each estimate.

Maintainability engineers prepare similar estimates, with maintainability typically measured in terms of mean time to repair (MTTR) and maximum maintenance man-hours (MMH maximum). Mean time to repair includes the time to identify and isolate the fault, repair the fault, and verify the repair. Thus it includes measures of both testability and reparability. MMH maximum is the maximum time required to restore an LRU to operational status after a failure. As in the case of reliability, these estimates are based on historical data, with appropriate multipliers to reflect differences in hardware or maintenance concept between the system under design and the system on which the historical data are based.

Maintainability requirements are usually expressed in terms of availability. For instance, a minimum number of airplanes must always be available for performing a mission. The reliability estimates for a particular design can be used to estimate how many airplanes will need repair at any time. The maintainability estimates indicate how long it is likely to take to return these planes to service. The total number of planes required in the fleet to ensure that the minimum number is

always available can be estimated from the reliability and maintainability projections. Maintainability estimates, along with indications of the methods used to obtain them and the data supporting them, are included in a maintainability design criteria document.

Early in the design process, logistics engineers analyze the system requirements and prepare a use study based on an analysis of system functional requirements. This analysis identifies system functions and the support and secondary functions they imply. The use study reflects the way the system will actually be used in practice and is the basis for all supportability estimates. These estimates include such things as personnel levels, skills, tools, and facilities required for maintenance and readiness and spares costs, including handling, storage, and transportation. The logistics engineers prepare a system comparative analysis model for the system under design and use this to estimate the supportability costs of each alternative being considered.

The major task of the supportability engineers throughout the design is the preparation and maintenance of the logistics support analysis record (LSAR), a large database covering all aspects of operational and maintenance data for the system being designed. For the B-1B, for instance, this database includes over 200 separate parameters for each of over 33,000 parts, in addition to mission profiles, operating environments, system requirements and specifications, operational and maintenance requirements, reliability and maintainability data, failure modes and effects analyses, failure criticality data, maintenance task summaries and predictions, personnel and support equipment requirements, training and technical data requirements, test procedures, facilities requirements and utilization plans, support items (tools, chairs, testers, etc.), transportability information, and handling instructions.

These reliability, maintainability, and supportability estimates are included in the data supporting life cycle cost projections for the various alternatives. Furthermore, the choices among the alternatives under consideration may be influenced by the reliability and availability estimates independent of the influence of these estimates on life cycle cost projections.

**Weaknesses of Analyses.** An important aspect of trade studies comes into play here. At the early stages of a design, there is little detail, and there is a multitude of designs expressing any design concept. It is logically impossible to determine the quality of a design concept more accurately than the range of quality of all of the possible designs expressing the concept. Attempts to do so depend on some explicit or implicit assumption about the choices that will be made in elaborating the design. Some of these, such as an assumption that the worst possible designs will be avoided, are usually justified. However, the point of a trade study is to choose among plausible alternatives on the basis of the particular requirements of the system under design. Basing estimates on historical data implicitly assumes that the basis for choice is constant across designs. The resulting projection reflects a single point in a range of values, and a significant part of the range corresponds to values for various design parameters that lie within the realistic design space.

This dependence on historical data to predict the future is associated with a second problem. A major reason for performing trade studies is to reduce risk, and the highest perceived risk in a design is often associated with a new technology. However, evaluation methods based on experience with similar designs are weakest in such a situation. The new technology has likely been explored in research and development efforts, but any historical reliability data are going to be less complete and reflect less realistic experience than similar numbers for designs with extensive field use. Thus the historical data underlying trade studies are likely to be least reliable in exactly those situations when they are most important.

Finally, the goal of concept exploration is a parameterized concept. Ideally, trade studies are applied to a range of possible values for the parameters in question, and one of the criteria used in evaluating designs is robustness; that is, insensitivity to small changes in the parameters characterizing the

design. Once again, evaluation methods providing point analyses based on historical observations of particular design elements are particularly unsuited to a trade study of a parameterized design.

The success of these methods depends heavily on the conservative nature of design. In the end, the system being designed will not be radically different from those providing the historical data, so the estimates based on the historical design choices will not be unreasonably wide of the mark in most cases. Nevertheless, in the early stages of the design, the chief value of these estimates is more in calling attention to the areas of highest risk of a particular concept than in predicting the actual value of any system parameter.

**Actual Flow.** The design process in practice is not as linear as it would appear from this description. As a result of trade studies, new alternative functional flows and functional block diagrams may be developed, perhaps combining the best parts of several of the alternatives studied. Further trade studies may be performed to guide a choice among alternative combinations. This process continues as long as the schedule permits. Then the best alternative is selected and evaluated to confirm that it meets all system requirements and involves acceptable levels of risk for the remainder of the design and production process. Because of this iteration, many of the more complex estimates, including those of reliability, maintainability, and logistics, may be performed only at the end of the process, when they serve to confirm choices rather than to provide information on which to base choices.

### **3.2.4 Specification Preparation**

The most important product of the system design effort is the system specification. This reflects the outcome of the trade studies and defines the system as a combination of subsystems corresponding to the blocks in the functional block diagram.

The specification details the constraints and allocated requirements on each subsystem. Many of these requirements are derived requirements that appear nowhere in the system requirements but must be met by the subsystem if the resulting system is to meet the system requirements. For example, the requirements for the avionics subsystem will include space budget, weight budget, cooling concept, cooling budget, and power budget. It is unlikely that any of these parameters was defined for the overall system. They are all requirements derived from the system requirements in the context of the selected system design and levied on the avionics subsystem.

In addition to functional requirements, the allocations include reliability and testability requirements prepared by engineers of the appropriate specialty. These allocations are based on the estimates described in the previous section as they apply to the alternative finally selected. These allocated requirements should represent the most achievable distribution among the subsystems that will enable the total system to meet its requirements of reliability and availability.

An important part of this specification is the definition of the interfaces among the functional blocks. Success in developing each block in parallel depends on the completeness and accuracy of these interface definitions. In addition to interfaces between subsystems, any interface between this system and any other system will be allocated to one or more subsystems and defined in this specification.

This specification should, but rarely does, discuss alternatives considered, trade studies performed, and the basis for the choices that were made. This information can help to clarify the specification. It can also save time if changes in requirements or unforeseen problems cause some portion of the system design to be modified in the future.



### **3.3 THE AVIONICS SUBSYSTEM LEVEL**

Each of the subsystems described in the specification produced by the system-level effort becomes a separate design problem for the next level. If the system being designed is an airplane or missile, one of the subsystems will be the avionics subsystem. We have chosen to concentrate on this subsystem in describing the remainder of the design process.

The avionics subsystem will be designed by a group of six to ten engineers with experience in this activity. Since there will be a design team for each subsystem, some new people must be added to those composing the system design team. In practice, the skills required are different, so an entirely new group of designers may be involved. In the case of the avionics subsystem, most of the design engineers will be avionics specialists, and the other members may be particularly experienced in the application of their specialty to avionics design.

The systems engineering process will go through the same four steps as the overall system. The designers analyze the subsystem requirements to determine that they are complete and ensure that they are understood accurately. The designers next perform a functional analysis to identify alternative concepts for realizing the design. They use trade studies to choose among the alternatives proposed and to validate the final choice. Finally, they document this choice in a set of specifications at the LRU level.

#### **3.3.1 Requirements Analysis**

The subsystem requirements are more detailed and more complete than was likely the case at the system level. However, the main goals of this step – to ensure that the requirements are accurately understood and to determine that the requirements are complete – are the same. In particular, there are usually many requirements such as military standards that apply to a design. It is likely that some specialized requirements that were unknown to the system designers will be recognized by the avionics subsystem designers. For instance, if an avionics system is to be used in a nuclear-war zone, various military standards specify numerous detailed hardware requirements that the design must meet. These standards would be known to engineers specializing in avionics but could be overlooked by the engineers at the system level. Once again, success in collecting all applicable requirements depends on the experience of the engineers involved.

#### **3.3.2 Functional Decomposition and Requirements Allocation**

Functional decomposition is significantly different at this level than at the system level due to the additional detail available. The goal of design at the subsystem level is to decompose the design into a collection of functional units at about the level of an LRU, although there may not be an exact one-to-one mapping between the functional units identified at this level and the LRUs in the final design. Frequently the customer has identified a list of existing equipment that will be included in the final design. As a result, large parts of the cooling, power, size, and weight budgets are fixed and only a restricted portion of the total design is available to adapt to requirements. In these new portions, the engineer draws heavily on experience. The goal is to find existing designs that satisfy the requirements or can conveniently be modified to do so, not to find the best possible solution to the design problem. The point is not that optimum designs are avoided, but rather that the psychology of design is to find a satisfactory solution as efficiently as possible. Herbert Simon (Reference 5) has referred to this approach as "satisficing" and pointed out that it enables one to find satisfactory solutions to problems that are too complex to allow finding the optimum solution. It is likely that satisficing performance requirements is the optimum technique for meeting schedule and budget constraints. A design based on existing elements is faster and less risky to produce than a completely new design.

The first step in functional decomposition is frequently a brainstorming session. High-level functional flow and functional block diagrams may be prepared, or the participants may make their own mental functional decomposition. The goal of the brainstorming session is to produce a set of design possibilities, usually based on existing designs. The participants rapidly settle on two or three alternatives for further analysis. Although the approach to design performance is satisficing, in the sense that a new design will rarely be considered if an existing design meets the requirements or comes close to doing so, there is some informal optimizing in determining which existing designs to consider and in choosing two or three for further development. The avionics problems being addressed are rarely completely novel, and the engineer implicitly draws on the knowledge accumulated over years of solving similar problems to choose the best existing designs to satisfy the current requirements. On the other hand, the only experience that can influence the design is the experience of the members of the design team. It is likely that significant portions of the potential design space will not be considered because of the necessary selectivity of this accumulated experience.

At this point, more detailed functional flow and functional block diagrams can be constructed from the documentation of the existing designs. Subsystem requirements are allocated among the functional blocks to ensure that the design meets the requirements. As in the previous stage, this allocation involves both requirements specified for the subsystem and derived requirements arising out of the functional decomposition being considered.

### 3.3.3 Trade Studies

The choice among various design alternatives is based on trade studies. A major goal of the design process is still to reduce risk, so trade studies must be concentrated in the areas of highest risk. A trade study should not be performed in areas where the outcome will have little impact on the cost, performance, or schedule of the final product. There is no formal technique for determining when trade studies should be conducted. The ability to choose well varies from engineer to engineer based on experience, training, and aptitude.

The chief difference between the trade studies performed at this level and those performed at the system level is that more detail is available, so the estimates are more accurate. Since the design is based to a large degree on existing designs, the estimates can be based on the corresponding parameters in those designs. If the design involves modification of an existing design, the engineer estimates the similarity (e.g., "this object will require about 1.5 times the circuitry of the existing design"). Cost estimates are prepared by specialists.

A packaging engineer develops estimates of system size, weight, hardware, and interfaces. These estimates are based on similar predictions for each LRU. These, in turn, are based on projections of the size and weight of each board in each LRU. These estimates may be modified by nuclear hardness and survivability requirements. On the basis of these estimates, the packaging engineer also predicts power and cooling requirements and order-of-magnitude packaging engineering costs for the system. A manufacturing engineer prepares an outline manufacturing plan and statement of work on the basis of the packaging estimates of size, weight, hardware, and interfaces. Based on these outlines, the manufacturing engineer predicts manufacturing engineering, tooling, and production costs for the design. Manufacturing also estimates the producibility and testability of the proposed design. The packaging and manufacturing cost estimates contribute to the production and life cycle cost estimates prepared by Logistics Support.

Reliability, Maintainability, and Logistics Support provide the same types of data they did at the system level. These estimates address the ability of each design alternative to meet reliability, maintainability, and testability requirements that have been allocated from the system level. However, the estimates are much firmer at this stage because of the increased level of detail of the

design. They are still based on estimates of similarity to historical data, but the granularity is finer, so the historical data are more accurate and the similarity can be determined more precisely.

Trade studies address technical questions. For example, an engineer might use a trade study to determine what level of redundancy is desirable. Increasing redundancy increases availability, but it also increases such things as cost, weight, power and cooling demands, and spares requirements and decreases reliability measured as MTBF, since the added circuitry increases the number of potential failure sites.

A trade study might also be used to determine whether a circuit should include direct monitoring for fault detection, fault detection circuitry activated at user request, or other options for fault detection. Direct monitoring should enable faults to be detected soon after they occur, but it requires extra circuitry, which increases the cost and complexity of the final design.

If the object being designed must survive in a nuclear-war zone, features must be added to the design to protect it from electromagnetic pulse (EMP), radiation, and other effects of a nuclear blast. However, each of these features provides new opportunities for failure. Thus, increasing the probability of surviving the effects of a nuclear detonation decreases the overall availability of the object. These effects must be estimated as accurately as possible so the design can strike the best possible balance for the mission at hand.

The trade studies balance the costs of the various impacts against the constraints and requirements of the particular design problem being addressed. These studies are decided on the basis of cost, schedule, performance, and function, usually in about that order. Considerations of reliability, maintainability, and producibility are not drivers of the design. These specialties are regarded as problem identifiers rather than as design collaborators. They may require that a choice be changed, but they do not participate in or influence the actual process of choosing. The designers' responses to such problems range from questioning the basis of the estimate to modifying the design to address the identified problem. It is unlikely that a choice will be totally eliminated on the basis of reliability, maintainability, or producibility. If it is, the choice among the remaining alternatives will once again be made on the basis of cost, schedule, performance, and function and submitted to reliability, maintainability, packaging, and manufacturing engineers for analysis.

### **3.3.4 Specification Preparation**

Subsystem design is not a single linear process. As a functional block diagram is prepared at some level of detail, further analysis of each block may become the task of an engineer specializing in that particular aspect of avionics. For each functional block at each level, a different engineer is likely to take detailed responsibility. This process results in an engineering team whose structure reflects the functional tree of the item under design.

The avionics subsystem requirements are usually contained in the segment specification. At each level of decomposition, a detailed interface definition document (IDD) is prepared for each interface between functional blocks. The requirements for each functional block are collected and passed to the engineer responsible for the further design of that block. Depending on the size of the system being designed, there may be some intermediate specifications of portions of the avionics subsystem and their interrelationships.

The next formal specification will be the configuration item specification. In an avionics system, each configuration item is about the level of an LRU. The development of specifications at that level is discussed in Section 3.4.

### 3.4 THE EJECTOR STORES INTERFACE UNIT LEVEL

One of the LRUs on the B-1B is the ejector stores interface unit (ESIU) (Reference 3), which is part of the avionics for the SRAM-II weapons system. The formal specification for the ESIU is a configuration item specification. Ideally, the first part of the configuration item specification is prepared by Systems Engineering before detailed design starts. In practice, there is extensive overlap between these two activities, largely because of schedule constraints but also because the system's function cannot be completed without some of the detail provided by the hardware design. The design may be carried to great detail before the designers commit to a novel approach perceived to be associated with high risk.

Although the Systems Engineering portion of the configuration item specification is usually not complete when detailed design begins, some document is required to communicate the LRU requirements to the hardware designers. The hardware implementation requirements document fulfills this role. It is usually not a contract deliverable, although it is available to the customer. It can be changed more readily than a formal design deliverable and addresses the reality that system design and hardware design necessarily proceed in parallel and support each other at this stage. It plays the functional role intended for the configuration item specification; the latter document has become largely a contract formality that documents the final design but plays no role in producing that design.

#### 3.4.1 Requirements Analysis

Implicit requirements that may not have been considered at higher levels must be identified at the LRU level. For example, the initial requirement for the ESIU was to enable the B-1B to carry SRAM-II missiles. Unstated were all of the requirements that apply to it because it is one or more LRUs that function as weapons interface units on the B-1B. These include general requirements applying to all B-1B programs, special requirements applying to all B-1B LRUs, and further special requirements applying to B-1B weapons interface units. These requirements include such things as cooling concepts; size, weight; interface definitions; reliability, availability and maintainability requirements; and survivability requirements.

#### 3.4.2 Functional Decomposition and Requirements Allocation

The first major design decision is whether to modify an existing LRU or design a new one. The main activity at this stage is brainstorming for alternatives, which are usually combinations of newly designed hardware with existing hardware or modifications thereof.

For each option, the new hardware and modification of existing hardware required are analyzed. A functional design at the circuit level and an IDD are prepared for each option. An estimate of wires and circuit boards is made for each alternative. Manufacturing cost, power, weight, and cooling are estimated on the basis of wires and circuit boards. The design engineers estimate reliability and maintainability on the basis of the number of LRUs and circuit boards. Weight and power are estimated for each option. None of these estimates is based on any formal rules or history. They are informed estimates made largely by the engineers in the design group. For maintainability, for instance, the basic rule of thumb is that the more components there are, the more likely it is that one will fail and the more difficult the overall design is to maintain. The estimates for an alternative are documented in a hardware description like the example in Figure 10. On the basis of these estimates, one of the alternatives is selected for further study. In making this choice, the most influential considerations are still cost, schedule, functionality, and performance.

End item:	Ejector/1760(ESIU), 8 MSL
Configuration item:	To be determined
Similarity:	Similar in complexity to 50% of a nuclear SLU, plus volume for high-bandwidth growth
Chassis:	7.5 in high x 12.5 in wide x 27.0 in deep (same size as D/R) Room for shock mount and sway space Braze air-cooled chassis, inserts at 150 locations
Printed circuit card assemblies:	9 unique printed circuit card assemblies 10 total printed circuit card assemblies 35 spare printed circuit card assemblies Same size as B-1B RDT New SCD connector
Electronic parts:	Same surface-mount very large scale integration and hybrid technology
Power supply:	2 new unique modules Voltage regulator equivalent to 400-11006 Transformer rectifier equivalent to 110% of 400-11005
Relay modules:	2 new unique modules Same size as nuclear SLU modules Flex-rigid printed wiring Unlock module - 12 relays (4 solid state) Squib fire module - 10 relays (2 solid state)
High bandwidth (growth option):	1 radiofrequency amplifier 1 power divider (1 x 8) 8 coaxial relays equivalent to MIL-S-3928/10C 2 1 x 2 radiofrequency coaxial switches 18 electromagnetic interference filters equivalent to MIL-F-15733-61B-0006
Wiring:	Motherboard to make interconnections between SRUs Harness with 300 wires without high bandwidth 60 wires for high-bandwidth growth
External connectors:	18 connectors per MIL-C-38999 1 power 1 1553B 1 test 1 PCA control and status 4 MSL (8 preferred) 1 unlock enable 2 unlock 2 squib fire 5 high bandwidth

Figure 10. LRU Hardware Description

Up to this point in the design, there is little or no use of computer-aided engineering (CAE) tools to develop and document the design. Individual automated tools are used for analyses at various stages, but these are not integrated, and the overall design is not represented on any automated system.

Once one alternative is selected, it is explored in more detail. At this point, about half the input to the design effort comes from hardware engineers. The main activities are functional analysis and hardware interface definition. To support these explorations, the circuit is designed in some detail. Portions of it are developed to a breadboard, which is subjected to extensive testing. The decision of whether to carry the design to this point is based on familiarity. If part of the design is novel and there is some uncertainty about its development or behavior, it is a candidate for breadboarding and testing. Alternatively, a portion of the design may be entered in a CAE tool and tested by simulation. The goal is a design that can be produced with confidence.

Derived requirements are determined, and requirements at the LRU level are allocated to functional blocks within the LRU. At this point, the requirements are quite detailed. Interfaces are defined in terms of content and timing. The outcome of this stage will be a configuration item specification or equivalent. This specification is the basis for the detailed design described in Section 4.0.

### **3.4.3 Trade Studies**

There are two types of trade studies at this level. The early trades, which form the basis for choosing among alternative designs for the LRU, were discussed in Sections 3.2.3 and 3.3.3. Once one alternative is selected, more detailed information is available and more accurate trade studies can be performed to choose among possible implementations. At this stage, there is no formal definition of design alternatives. At some points in the design process, several options may be compared. At other points, the designer will choose the first option that works. The choice depends on the individual, his or her experience, the schedule, and the familiarity and criticality of the function.

Trades are decided on the ability of the design to meet the requirements. Once again, the driving considerations are cost, schedule, performance, and functionality. Functionality is a binary decision. The design is acceptable in terms of functionality as long as the requirements are met. Performance is a graded decision. A design offering more than the minimal performance may be chosen, particularly if it has something to offer in another area. Failure mode analyses help determine where redundancy is required for the design to meet reliability requirements.

As described in Section 3.3.2, manufacturing and packaging engineers contribute to the cost estimates. The added detail available at this point means that these estimates can be more accurate and detailed. Furthermore, packaging engineers produce a parts list for the design and may also perform thermal, stress, and vibration analyses. The added detail of the design and packaging estimates enables manufacturing engineers to prepare a more detailed manufacturing plan and make more detailed and reliable estimates of manufacturing flows and costs. The purposes of the packaging and manufacturing analyses are to support life cycle cost estimation and to identify problems in the design. Their function is to approve the design from the perspective of manufacturing and packaging rather than to actively contribute to the design.

Reliability is a direct consideration in the production of the design at the level of required redundancy. For instance, if a function is required to survive a certain amount of battle damage or is critical to the total system, redundancy may be provided. Detailed predictions of reliability (MTBF and MCSP) and of maintainability (MTTR and MMH) are prepared, usually at the end of the process when they serve to confirm rather than contribute to the design.

### **3.4.4 Specification Preparation**

The outcome of this stage in the process is part of the configuration item specification or its functional equivalent, the hardware implementation requirements document. The initial requirements have been refined into a specification on which a hardware engineer can base a design. The specification has been analyzed in sufficient detail to provide confidence that it can be met and that all of the original design requirements will be met by the specified configuration items interacting through the documented interfaces.

## 4.0 DETAILED DESIGN

### 4.1 OVERVIEW: LRU DESIGN

This section describes the process typically employed to design a deliverable end item (a line-replaceable unit (LRU) or electronic assembly that is delivered to the customer), given a relatively detailed definition of the item's design requirements. To simplify the description of the design process, the following discussion is based on the process used to design the internal circuitry and the physical characteristics, both internal and external, of an LRU roughly the size and complexity of the B-1B ejector stores interface unit (ESIU) described in Reference 3.

The design functions considered part of the detailed design process include (1) developing a detailed functional design of an LRU's circuitry, (2) designing software and electronic hardware elements that implement the intended functionality of the LRU (the software development process is not discussed), (3) designing the physical attributes of the LRU, and (4) developing a manufacturing dataset and plan upon which the initial deliverable LRUs will be produced. The difference between this phase of the design process and that discussed in Section 3.0 is that the end products of this phase are engineering drawings, specifications, and requirements that detail how the LRU is to be built.

Although detailed design functions are often performed prior to full-scale development (FSD), for example during the demonstration and validation (D/V) phase to support prototype hardware development or assess the feasibility of a design concept, this report focuses on the process and tasks employed in the design of a deliverable LRU. The term "detailed design" refers to those tasks involved in designing a deliverable end item from an initial definition (requirements and specifications) of an LRU. Typically, this includes all tasks beginning after the system design review (SDR) and before the production phase begins. Both the preliminary design review (PDR) and the critical design review (CDR) are considered to occur during this phase of the design process.

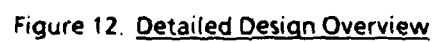
A simplified view of the detailed design process is shown in Figures 11 and 12. Figure 11 shows the basic dependencies among the top-level detailed design functions. Figure 12 shows the basic data flow between the major detailed design tasks. In general, the flow of information is from circuit design to packaging design (and the supporting analyses) and then from packaging design to manufacturing design (and the supporting analyses). This figure shows that, for the most part, first circuit design and then packaging design drive the detailed design process. The other design functions noted in this figure provide supporting roles. Current design techniques require some level of circuit definition before the physical design can proceed much beyond the conceptual phase. Similarly, some level of physical design must precede those tasks in which manufacturing issues are addressed or supporting analyses such as thermal analysis are performed.

Circuit design includes all the tasks associated with defining the electronic circuitry (both analog and digital), including logic design, initial component selection, test connector design, and similar tasks. Packaging includes those design functions associated with the implementation of the circuit in hardware, including the design of circuit boards (component placement and routing, board construction), LRUs (board placement, thermal management), and mechanical hardware (selection of connectors, design of LRU enclosure), and other functions. Manufacturing design is concerned with ensuring that (1) the design of the LRU can be produced cost effectively and has sufficient testability to support manufacturing acceptance and quality assurance tests and (2) product quality can be maintained.

The Reliability organization prepares and publishes early in this phase of the effort a formal document containing a reliability design guidelines report - *Reliability Design Criteria and Requirements*. This report defines guidelines for the circuit design engineers to enable them to proceed with their designs. These guidelines include (1) part selection; (2) part derating; (3) identification of undesirable parts; (4) stress analysis requirements and instructions on how to fill out







the basic detailed design tasks and functions cannot be effectively shown. Well over 200 separate analyses could be performed during the design of an LRU the size and complexity of the ESIU. In some cases, the analyses that are performed and the degree to which they affect the design are a function of schedule and cost. The figures do not show the many studies or analyses that are informally conducted to develop preliminary information. We have elected to describe only those analyses that, for one reason or another, are more frequently used. It is not possible, within the scope of this paper, to fully describe the constraints and difficulties the design community faces in designing a complex electronic subassembly.

It should also be noted that although these figures show specific, distinct tasks and their sequencing, in practice the division between one task and another is less well defined. Schedule pressures and the iterative nature of the design process often result in design tasks being conducted in parallel where they are shown sequentially or as one task where they are shown as several.

## **4.2 PRELIMINARY LRU DESIGN**

The basic subtasks performed within this task are shown in Figure 13. Ideally, the initial phases of detailed design should be a continuation of the systems engineering effort to develop detailed functional requirements and characteristics at the board and circuit level from requirements and specifications (e.g., configuration item specification, part 1) defined at the LRU level. Depending on the state of the design (e.g., level of definition, completeness, and consistency of the requirements and specifications) and the involvement of the detailed designers in the systems engineering tasks, the transition from systems engineering to detailed design may be a smooth, relatively painless transition or, as is often the case, a chaotic period in which circuit design begins without a complete and consistent definition of the circuitry that must be designed. This latter situation often arises on projects that have compressed schedules or insufficient funds to enable a thorough and methodological derivation of requirements at the circuit level from those defined at the LRU level and above. Realistic requirements require the involvement of designers and engineers from both Systems Engineering and Detailed Design organizations. In practice, the design of the circuit logic is an iterative, evolutionary process in which partial solutions are proposed and then evaluated against the requirements. This becomes particularly difficult when, in general, several system engineers, circuit designers, packaging designers, and manufacturing engineers are involved to some degree in designing the electronics of a single LRU.

In any event, the first task is normally to attempt to become familiar with the overall system concepts and to understand the impact of both the stated and unstated (i.e., implied by reference) requirements on the functionality and performance of the LRU. Ideally, this is a joint effort between systems engineers and the detailed circuit designer. Often, however, the designer of the detailed circuit is left to his own devices to interpret and understand the impact of requirements levied on the LRU by Systems Engineering.

### **4.2.1 LRU Functional Design**

Using a functional decomposition and analysis approach similar to that used during systems engineering, each LRU function is further defined in terms of requirements for parallel and serial supporting functions that collectively provide the needed functionality. If necessary, each supporting function is further decomposed until the functions defined appear to be at a level low enough for circuit logic or specific components capable of providing the required functions to be visualized. The overall strategy normally used is to incrementally develop the requirements by working from the external interfaces of the LRU circuit inward, using those elements of the design that exist (e.g., standard circuit) or are well understood to both check and refine the requirements. In effect, requirements are propagated from the external interfaces of the LRU to other elements of the design in the form of constraints.

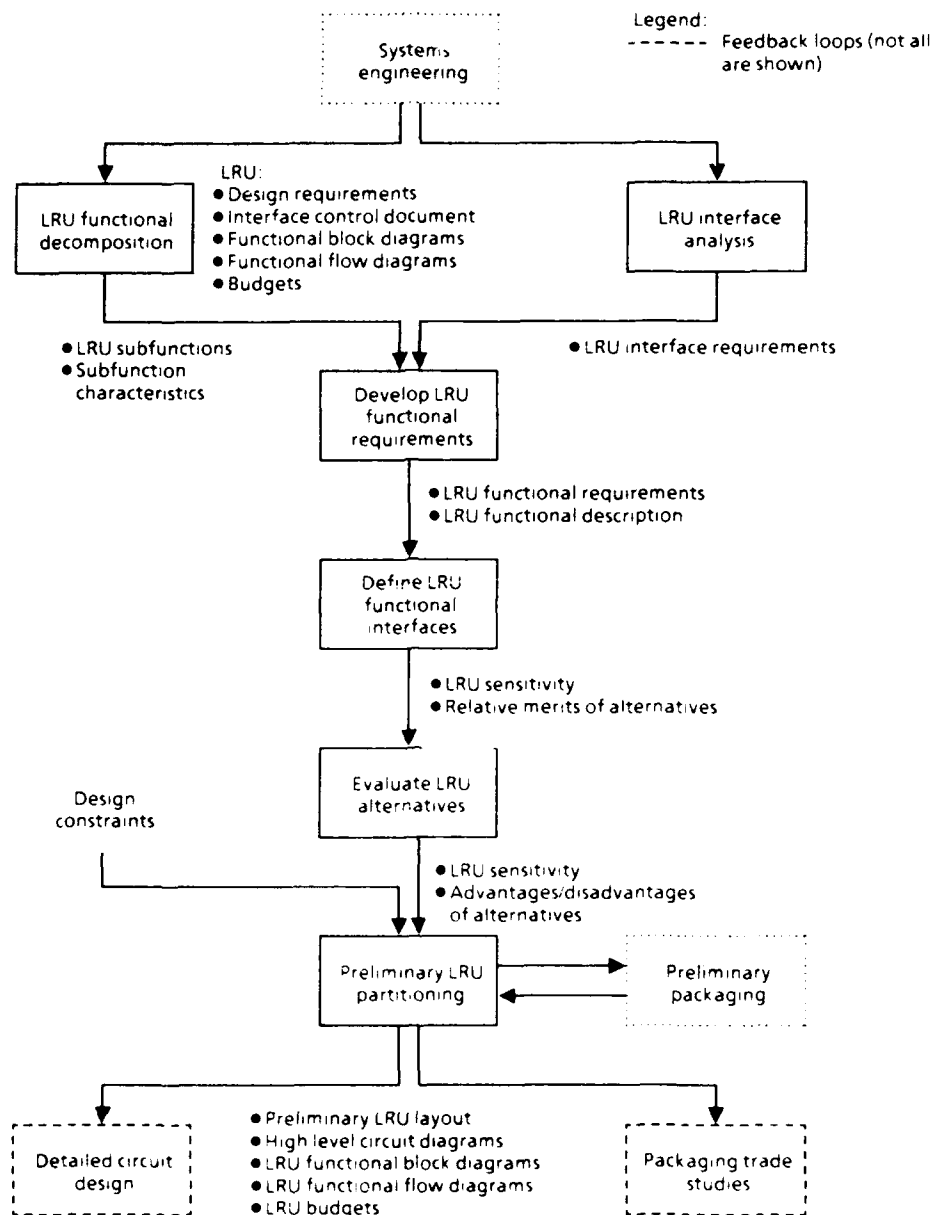


Figure 13. Preliminary LRU Design

For example, the ESIU "release store" function is further defined in terms of three supporting functions: (1) "retract the store-release locking pins" (pins preventing the inadvertent release of the store), (2) "retract the arming pin" (retraction of the arming pin arms the store), and (3) "trigger squibs" (to eject the store from the aircraft). An initial set of requirements associated with these lower level functions is developed by identifying the interfaces associated with each and determining the requirements associated with each interface. In the example, external interfaces to the store and to the electromechanical linkages between the ESIU and the store define the initial requirements for

the "release store" function. The characteristics of the solenoids used to retract the locking and arming pins define the voltage, current, and timing requirements of the first two functions. Similarly, the squib characteristics define requirements for the "trigger squibs" function. Additional requirements are derived from the applicable military and Boeing standards as the design progresses and the interfaces between circuit elements internal to the ESIC are defined.

The difficulty faced by a detailed design engineer (a detailed circuit, packaging, or manufacturing designer or engineer) in trying to understand the impact of a myriad of DOD and contractor requirements and regulations on the design should not be underestimated. Typically, the designer will see a requirement such as "95% fault isolation" that must somehow be implemented or enabled in circuitry. Unfortunately, guidance is seldom available on meeting the requirement or verifying its implementation. In practice, approaches that appear compatible with system requirements and the applicable standards are considered acceptable.

#### **4.2.2 Initial Line Replaceable Unit Partitioning**

Once a high-level definition of the circuit logic has been developed, a preliminary cut at partitioning the logic elements into major functional blocks is made. This is the first step toward designating which functions will be grouped together on a circuit board. Assignment of functions to individual partitions is based primarily on functional similarity, area and power requirements, number of interfaces, and any known constraints that dictate the physical proximity of particular functional blocks (e.g., computer processor and memory should be on the same circuit board). If possible, the LRU is partitioned so that the number of interface signals between partitions is minimized, "standard" interfaces (e.g., a military standard data bus) between the partitions can be employed, and each functional block consumes no more than 80% of the average available board area.

This initial partitioning serves two purposes. First, it partitions the LRU in a way that enables several circuit designers to work on it concurrently with a minimum of interaction. Second, it provides an initial cut at the circuit board to enable (1) Packaging Design to assess the need for connectors, monitor outputs (e.g., light emitting diode (LED) and liquid-crystal display (LCD) displays), and special packaging requirements and (2) Design Assurance to refine the failure modes analysis (FMA) initiated during systems engineering.

If the program schedule and resources permit, trade studies may be conducted to assess the relative merits of alternative design configurations or elements (e.g., components, standard circuits) that provide the required functionality. The studies seldom follow a formal procedure; they usually consist of informally listing the advantages and disadvantages of the alternatives and subjectively assessing their merits and are, for the most part, undocumented. The studies rely heavily on data from previous design evaluations and often become a "deselection" process - identifying factors that eliminate alternatives - instead of a trade study. Decisions at this stage in the design process are a function of the level of detail in the design. Specific components or standard circuits may be selected if the level of detail in the design permits.

Although the major drivers at this stage are function and performance, other design parameters are considered to some degree, according to the ranking shown in Table 5. This table gives an indication of ways the detailed designer satisfies the requirements associated with each design parameter. Board space, power allocations, cooling capacities, and weight are typically allocated to the LRU level prior to this point by negotiation between systems engineering and detailed design engineers. Although the Detailed Design organization has a voice in these allocations, system-level considerations often overshadow those at the LRU level, and "budgets" for these parameters are often less than requested. For this reason, these and other design parameters are viewed primarily as design constraints and selection or deselection criteria for the detailed designer. In most cases, they are used to restrict the design space and reduce the number of alternatives studied in depth. Only those alternatives that appear to offer designs likely to fall within the limits prescribed by the

**TABLE 5. Detailed Design Considerations**

Parameter	Considerations
Function	Alternate implementations, tolerances, past designs
Performance	Speed, technology, precision
Input/output specifications	Serial versus parallel, protocol, timing, failure modes
Power	Allocation, dissipation, isolation
Size	Number of boards, board area, future enhancements
Radiation	Part selection, data distribution, nuclear/EMI/EMP, and fault tolerant features
Fail-safe and safety	Redundancy, hardware and software, mechanical and electronic
Built-in test	Type, technique, on line or off line, access to hardware, size, fault detection and fault isolation
Temperature and cooling	Preliminary layout, sinks
Electromagnetic interface and electromagnetic pulse	Part selection, preliminary layout, routing, filtering
Shock and vibration	Preliminary layout, technology, part selection
Pressure	High voltage, cooling
Weight	Part selection, part density
Cost	Parts cost, manufacturing cost
Testability	Observability, controllability, techniques, design rules, fault detection and fault isolation, false alarms
Reliability	Stress derating, redundancy, fault-tolerant design, buffering
Maintainability	Testability
Supportability	Preferred parts list part standardization
Producibility	Board density, design rules
Military standards	Guidelines, design rules

requirements are pursued to any degree. Environmental factors such as radiation and electromagnetic pulse or electromagnetic interference limit the components that can be employed within a design, introduce additional circuitry, or constrain circuit board layout and routing. Radiation, for example, limits part selection to parts certified as radiation hardened to the level called out in the specification (e.g., core random access memory (RAM)) or results in the incorporation of additional circuitry to restore operation following a nuclear burst (e.g., logic to reload dynamic RAM from nuclear-hardened read only memory (ROM))

Once the basic requirements (e.g., functional, performance, power) are met, the reliability and testability of the design are evaluated. If more than one alternative meets the basic requirement, decisions based on reliability, testability, and other factors are used to choose among them. Design alternatives appearing to be inherently more reliable or testable are typically chosen.

Reliability during this stage of the design is usually addressed qualitatively (certain classes and types of parts are believed or known to fail more often than others), and mean-time-between-failure (MTBF) reliability requirements are usually met by using components from an approved parts list. Other qualitative rules of thumb are used extensively, such as choosing design alternatives that require fewer components and using the latest and highest quality parts. Reliability is stressed only

when new technology is used; the reliability requirements specify a level that, from past experience, the designer feels may be difficult to meet; or there are concerns about safety. In addition to redundancy, other reliability design techniques, such as parity and error checking and correction (ECC), are considered.

Reliability and maintainability (R&M) issues affect two dimensions of the design, design assurance and field support. Although R&M issues may not receive the priority needed to ensure that maintenance and support costs are minimal, these issues are addressed when they impact design assurance or airworthiness. Maintainability and supportability are usually addressed only via testability requirements and the use of parts and components that have met the requirements of a screening process (an approved or preferred parts list developed by the Logistics Support organization).

Testability is typically addressed by assessing the criticality of each function and allocating test points to functions based on this assessment. Because detailed failure data are seldom available, the emphasis is on defining test points for all the critical functions first and then adding test points that discriminate between the failure of one partition of the LRU and another. If a test connector is needed, the initial partitioning of the LRU takes into account a rough estimate of board area needed for a test connector; generally around 10% of the average available board area is assumed. The degree to which testability is addressed appears to be highly dependent on the intended use of the LRU. Testability and fault monitoring are emphasized in any design that is part of a nuclear weapons system. As with other desirable design features, schedule pressures, limited board area or connector size, and/or lack of an effective design tool usually prevent testability from being as extensive or complete as it could be.

In many cases, the first design that appears to meet all the levied requirements is considered sufficient. Not much effort is spent going beyond the initial design in any area because of schedule constraints and cost concerns. Managers are reluctant to expend additional resources to improve an adequate design unless there is a high degree of certainty that the expenditure will pay off. Except in a few instances, the risk of expending resources without an effective return outweighs the potential benefits.

### **4.3 CIRCUIT DESIGN**

The major tasks involved in the design and verification of the electronic circuitry are shown by the shaded boxes of Figure 14.

It is important to note that, in general, circuit designers are not concerned with circuit-board issues while developing the detailed circuit logic. Maintainability or supportability issues are also not considered to any degree at the circuit and component level.

#### **4.3.1 Detailed Circuit Design**

Once a high-level circuit description has been developed and an initial partitioning of the LRU has been completed, detailed design of the electronic circuitry begins in earnest. The basic process for developing the applicable design requirements and constraints is essentially the same as that employed for the LRU – an analysis of the requirements associated with each function allocated to the partition and the interfaces the function requires. The interfaces associated with each function allocated to the partition are reviewed to determine whether they have changed during the time it took to get to this point.

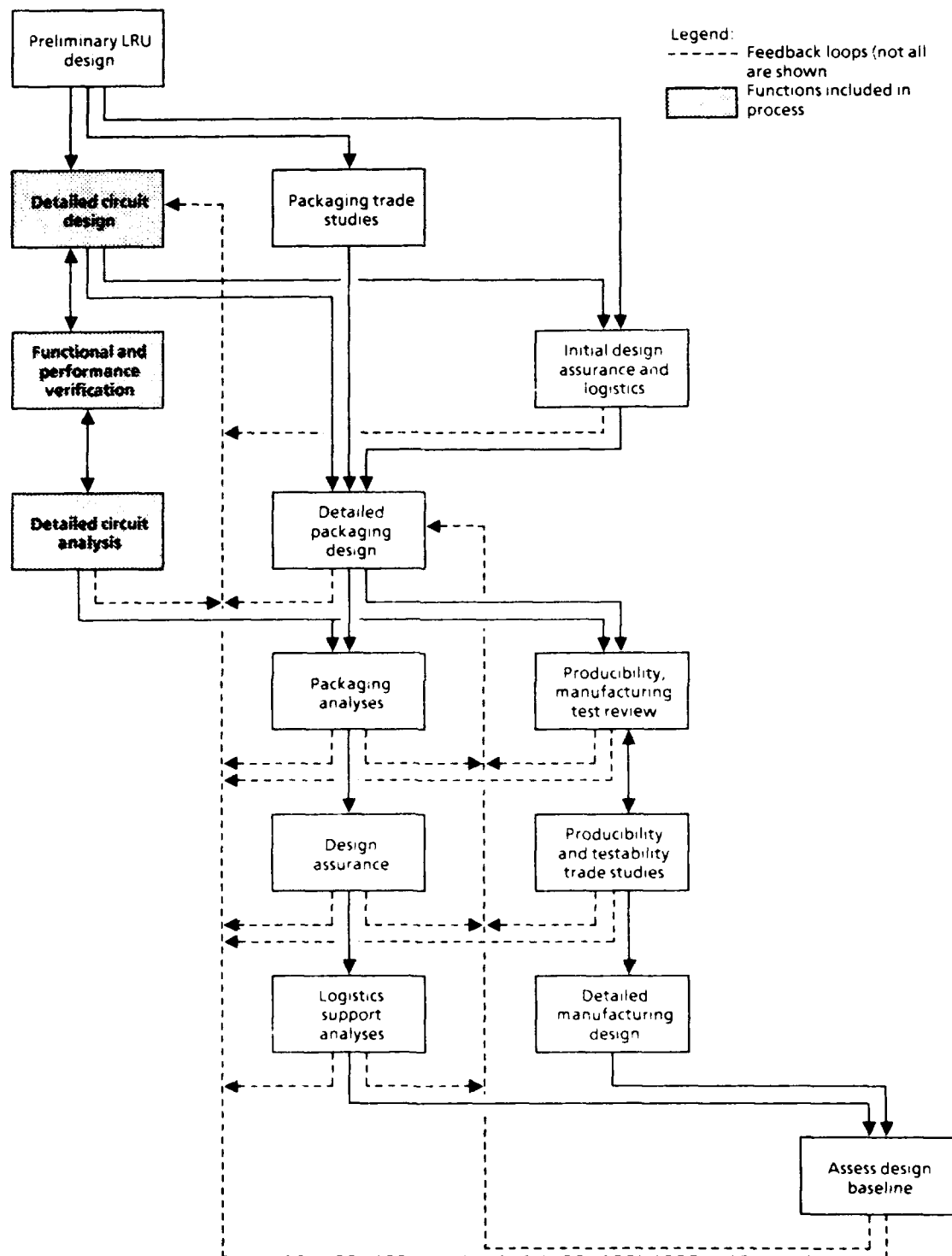


Figure 14. Circuit Design

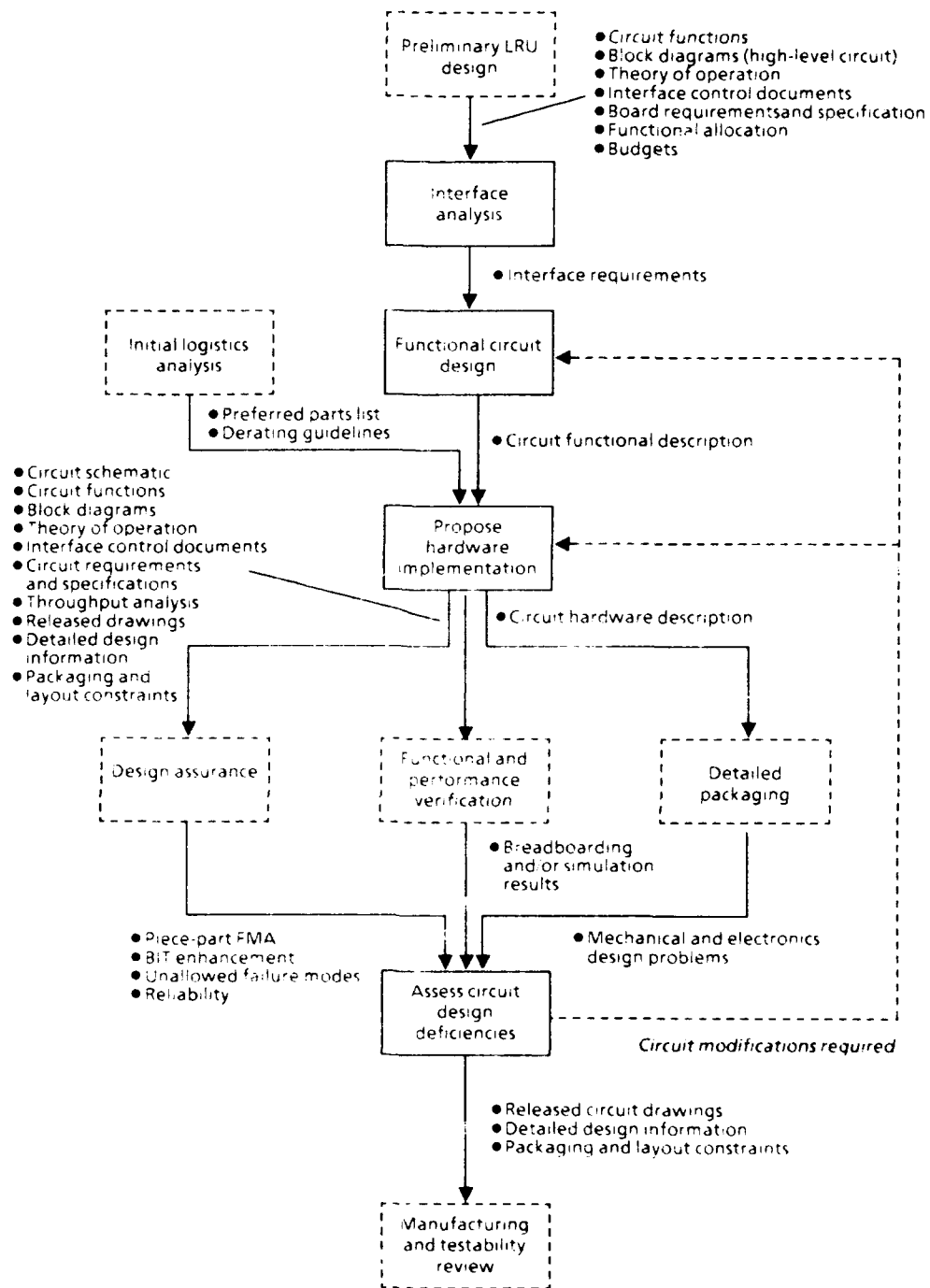


Figure 15. Detailed Circuit Design



Although Figure 14 indicates that detailed circuit design does not begin until a preliminary design of the LRU is complete, these two tasks may actually occur in parallel. Figure 15 shows the relationship of the primary design tasks involved in detailed circuit design.

Based on this information and the high-level functional block diagrams developed during the preliminary LRU design phase, schematic diagrams are developed that define the circuit logic and major component modules (e.g., power supplies). These diagrams are the functional equivalents of the detailed circuit diagrams that describe the hardware implementation of the circuit. Instead of specific components, however, the circuit logic is described in terms of generic functional blocks at the component level (e.g., AND gates, OR gates, latching logic blocks, comparator logic blocks).

If schedule and resources allow, trade studies or alternatives analyses are performed to determine the best hardware implementation of the required functions. Requirements and specifications are allocated to the circuit level from the LRU level so that any restrictions related to component selection or the use of a particular technology (e.g., gallium arsenide) are passed down. If no constraints are specified, the designer chooses among the various options according to his or her own preferences. As before, the trade studies are not a formal procedure and often become a deselection process.

Using the results of trade studies and design handbooks provided by the component part vendors, hardware components are selected that meet the functional and performance requirements of the circuit. As before, other design parameters, such as temperature, are used to deselect components that cannot meet all the design constraints. Within Boeing, the policy is to select hardware components from a preferred parts list (PPL), a list of components meeting certain minimum criteria, developed by a logistics support organization. If the PPL does not contain a needed component, the designer must seek an exception to use a component meeting the circuit requirements but not on the PPL.

If the design requires the use of custom integrated circuits (application-specific integrated circuits (ASIC)) the process described above is repeated at the microelectronic level.

Once some part of the detailed circuit design is defined, circuit schematics, block diagrams, and other relevant data are prepared. Any packaging and layout constraints, such as maximum signal path lengths or components that must be placed close together on the board, are documented. At the completion of an engineering management review of the design, a detailed description of the circuit is released to the Detailed Packaging Design and Design Assurance organizations (to continue the FMA in more depth).

Up to this point, electronic computer-aided design (ECAD) tools have not played much of a role in the design of the circuit.

#### **4.3.2 Functional and Performance Verification**

As the detailed design description evolves, the first checks normally performed are verifications of the circuit's function and performance (Figures 14 and 16). Proposed design alternatives are informally evaluated as they evolve to ensure that all specifications and requirements are met.

Simulation and breadboards are the two basic approaches to verifying the functionality and performance of a design. The choice between breadboarding and simulation is based on several factors, including program schedule, cost, available personnel and their skills, simulator hardware availability, model availability, circuit complexity, and the design requirements that must be verified. Although simulation is usually less expensive and requires less flowtime than breadboarding, other factors can prevent its use. Simulators and other ECAE and electronic computer-aided design (ECAD) tools capable of modeling the functions or computing the parameters

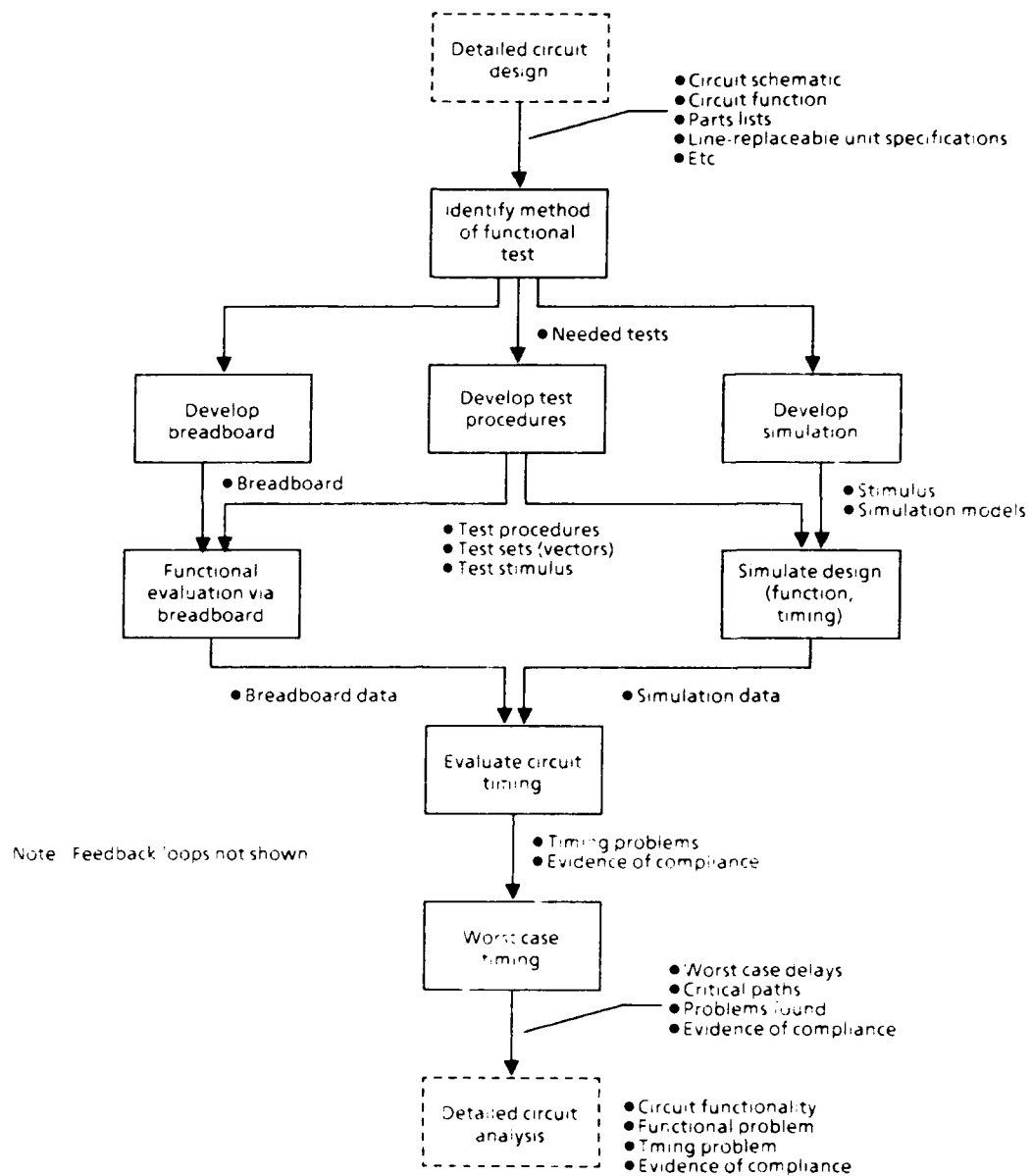


Figure 16. Functional and Performance Verification

to be verified must often be developed to support a specific design effort. Models of complex components such as microprocessors must often be crafted to suit a particular analysis and often take from 6 months to a year to develop. Circuits whose functionality is closely tied to software require that both the software and the hardware be modeled. Circuits incorporating components considered to incorporate proprietary technology, such as ASICs, can be simulated only if the vendor supplies a model of the device. Models for these devices are often not available from the supplier for proprietary reasons, and the circuit can be simulated only with actual hardware in the loop.

It should be noted that current-generation tools evaluate only a limited number of parameters and that one tool cannot do everything. Models of the components in the design must often be developed. This is particularly true if the design employs state-of-the-art design techniques or technology. These and other factors must be evaluated to choose the correct testing method. Boeing designers still prefer to use breadboarding to verify the functionality and performance of the circuit.

Test procedures and possibly the test stimulus are developed by the designer to verify the circuit. The circuit description (all the input data) is used to produce tests that exercise as much of the circuit as possible. The tests can be for several purposes. A test could verify that a design is functionally correct in regard to the requirements. A manufacturing test would be used to determine whether the design was built correctly, with the right parts in the right place. A maintenance test would be used to detect and isolate failures in a design. These tests can be very different from one another. For instance, a manufacturing test could be only a fraction the size and complexity of a maintenance test because a manufacturing test may need to test only one function in each component to verify the manufacture, not every function in each part to verify all functions. While detailed designers do not generally produce the actual manufacturing test set, they do provide the input needed to develop the best test to verify the design.

**Breadboard Approach.** The schematic "capture" data outputs of a circuit-design description (netlist and parts lists) are used as inputs to the breadboard-building process. Within Boeing, breadboards are generally created by Design Engineering unless some aspect of the circuit design (power requirements, circuit complexity, new technology) requires the expertise of a packaging engineer. Usually the breadboards are fabricated in an engineering shop instead of a manufacturing shop and are not subject to the same quality control or specification compliance requirements as a production board.

During development of the detailed circuit design and once the design schematics are captured, breadboards of the entire design or portions of the design are built. The breadboards are used by Design Engineering as a development tool to verify the circuit design functions.

Ideally, breadboarding and design verification are done before full-scale development (FSD) units are started. However, in many cases schedule pressures cause the completion of breadboard fabrication and verification to overlap the start of FSD-unit design. This can be expensive if the breadboard verification results cause major changes to the design, since FSD units are more expensive to design and build. This is a risk sometimes taken to meet schedules. Typically, LRU-level verification is accomplished with the aid of hardware prototypes and preproduction units.

**Simulation Approach.** As an alternative, but normally as an added task, a circuit may be simulated to verify the functionality and performance of the design. For the most part, functional simulation tests only the logical functions of a design. It does not generally take into account layout-related factors, such as trace capacitance, loading effects, or several other factors that can influence a design's functionality. Because of computer limitations, normally only a portion of a total design can be simulated if results are needed in a reasonable time. The biggest problem with simulation is lack of models for the components in the design. Model creation is complex and time consuming and generally cannot be done by the design engineer if the model is of a complex device.

The simulation is performed by running a set of test vectors through a design and recording the circuit and component outputs. The results are evaluated to check compliance with requirements and to develop enhancements to bring the design into compliance. With current technology, it is not feasible to simulate analog and digital portions of a circuit simultaneously.

### 4.3.3 Detailed Circuit Analysis

After the circuit's function and performance have been verified, several other circuit-level analyses are conducted to assess the characteristics of the circuit (Figures 14 and 17). Most of the following tasks are performed by the design engineer in concert with the development of the detailed circuit design. Other evaluations of the design (e.g., reliability, maintainability, FMA, failure modes and effects analysis (FMEA), failure modes effects criticality analysis (FMECA), logistics) are conducted by other persons or groups once the designer has completed the design of the circuit.

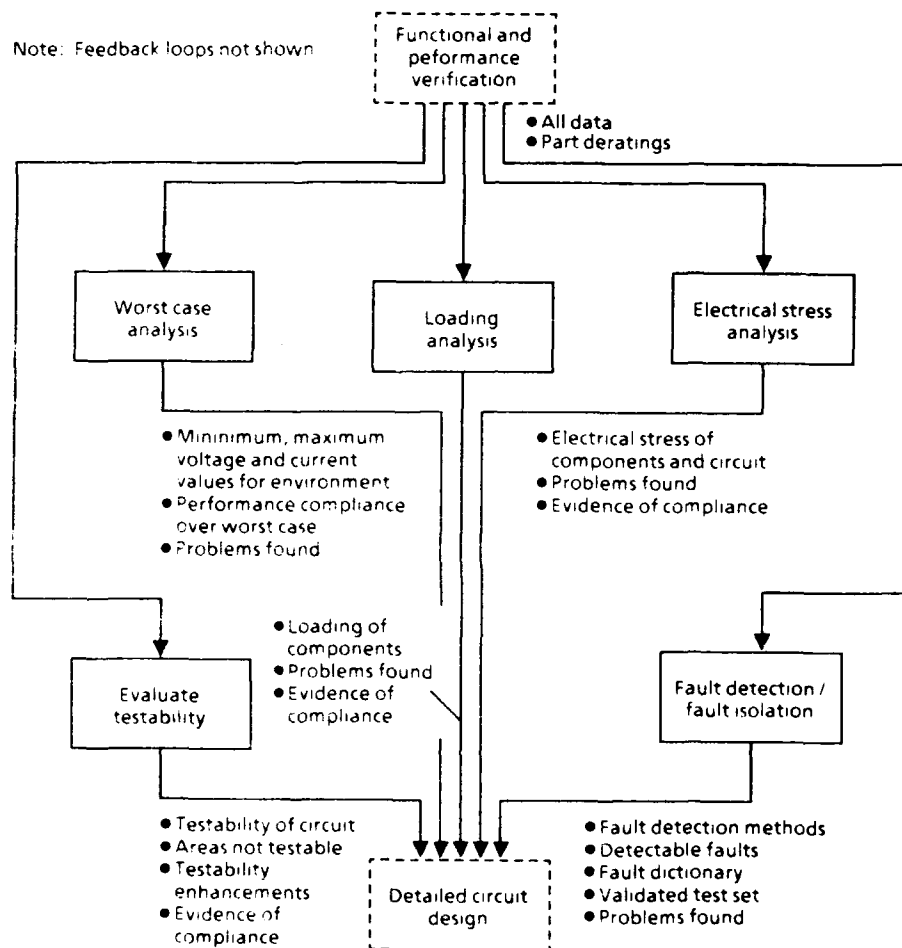


Figure 17. Detailed Circuit Analysis

**Timing.** Timing analysis is used to determine whether a circuit has a timing-related problem such as race conditions or setup and hold violations. The analysis can be either static or dynamic. A static timing analysis looks at the time delays on all gates and checks for any problems that could be caused if the delays varied over the predefined range of delays for each output. A dynamic analysis also checks the delay variations for each gate while the circuit is being simulated. This finds timing problems that are caused by the way a circuit is operated. A dynamic analysis can be done on either a breadboard or a simulator.

**Worst Case Timing Analysis.** Worst case timing and critical-path timing analysis of a circuit can be performed with the aid of either a breadboard or a simulator, or as an analysis of the timing specifications and the circuit description. The purpose of this analysis is to check for race conditions, setup and hold violations, and other timing-related problems caused by variations in the time-delay properties of components. These variations can be caused by variations in production quality, component suppliers, temperature, radiation, etc.

**Worst Case Analysis.** A worst case analysis is conducted to assess the circuit's performance in the presence of variations in component and production quality, temperature extremes, radiation, and other environmental factors. The purpose is to verify that a circuit will always meet its performance requirement under all operating conditions. For example, amplifier circuits typically have a nominal gain requirement that specifies an acceptable tolerance band.

**Component Loading Analysis.** Component loading analysis is used to compute loads driven by each output of the components in a design. An output can have two types of loading, AC and DC. AC loading is caused by the capacitance of the signal traces on the board and the capacitance of the inputs being driven. It affects the time delays of outputs driving the load. DC loading involves checking the current requirements of the inputs being driven and the ability of the output to drive to the needed output level. Derating specifications from the Reliability and Parts groups are used to decrease the maximum allowable loading to give a margin of safety.

**Electrical Stress Analysis.** Electrical stress is defined as the actual power dissipation over the maximum rated power dissipation for an electronic component. The actual power can be found by several means, such as simulation (generally analog only) or calculating the DC loading of each output and getting data from the part's data sheet. A derating factor is then used to limit the allowable maximum for an arbitrary safety factor to increase the reliability. These data are then used in the piece-part reliability predictions.

**Testability Analysis.** The degree of testability of an electronic circuit is determined by the ability to detect faults and isolate them to a specified ambiguity group under a set of test conditions. Although there are several approaches to determining the testability of a design, no single approach is believed to be adequate by itself. Among those normally used are several topological checks, such as checking for test point coverage and discrimination; use of reset or clear pins tied to a set value; breaking up counter chains; providing scan paths; and other design-related characteristics that can inhibit or enhance a design's testability. These checks are used to help locate areas of a design that are hard to test and, in some cases, aid in enhancing the testability of a design. A formal analysis may be done by Manufacturing test personnel, while the detailed designer usually does a more informal evaluation.

**Fault Detection and Isolation Analysis.** The purpose of this analysis is to assess the ability of a test set to detect and isolate faults in the circuit. Generally the effectiveness of the circuit's fault detection and isolation features is determined by computing the percentage of faults that are successfully detected and isolated to a predefined ambiguity group for a set of test vectors. The test vectors are developed by the design engineer based on his or her understanding of how the circuit operates. This analysis provides data for maintenance documentation.

#### 4.4 DESIGN ASSURANCE

Much of the design assurance function is provided by the FMA, FMEA, and FMECA. Figure 18 shows the relationship of the design assurance tasks to the other design tasks involved in detailed design.



#### 4.4.1 Failure Modes Analysis (Piece-Part Analysis)

The failure modes (piece-part or component) analysis usually follows the PDR. It is a process in which each component within the LRU is analytically failed (commensurate with its respective failure mode) and the results analyzed to determine (1) if the fault is detected or undetected, (2) the system operating mode in which the detection would occur, and (3) the impact and criticality of the failure on the system. The analysis can result in a redesign of the operational or fault detection circuitry to ensure that the fault detection and fault isolation (FD/FI) requirements for each LRU are met.

Although it can begin earlier than shown in Figures 18 and 19, the piece-part analysis consists of identifying and grouping together components that would provide a similar fault indication if they failed in a respective failure mode. The results of this analysis includes a complete fault description,

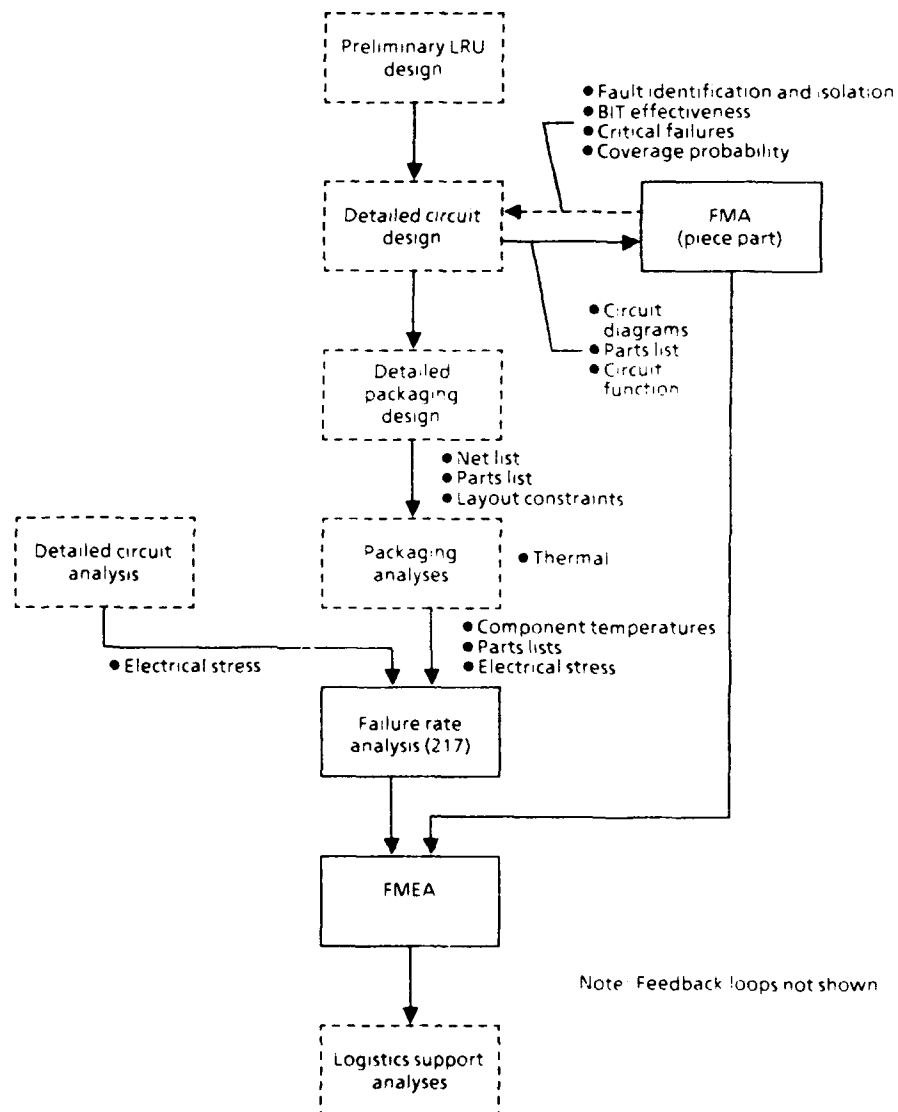


Figure 19. Design Assurance

the detection mode, system-level indications (how the fault is manifested at the monitoring station), and system impact when such a failure occurs.

The initial piece-part analysis must to be completed by the CDR for each unit in the system. After the CDR, when stress data are available for the components of an LRU, the piece-part analysis is revised to incorporate these failure-rate-per-component data.

If available, component failure rate data are used to reduce uncertainty about where the failure impacts more than one LRU.

Fault response sheets (FRS) are used to document the planned method of detecting and isolating failures, including any necessary sequencing of maintenance actions. FRS preparation is initiated between PDR and CDR. Applicable interface and piece-part analysis data are condensed and incorporated into each FRS.

#### **4.4.2 Failure Modes and Effects Analysis**

The FMEA is conducted to identify potential design weaknesses through a systematic, documented analysis of all likely modes of equipment failure, the causes of each failure mode, and the effects of each failure mode. FMEAs may be performed at the part, component, LRU, subsystem, and system levels, with the system-level FMEAs usually receiving the emphasis.

In performing the FMEA, the following items are considered:

- a. LRU and component failure modes.
- b. Likely causes of failure (obtained from lower level FMEAs).
- c. Mission timelines and mission profiles.
- d. Failure effects on adjacent components.
- e. Failure effects on the system and mission:
  1. Complete loss of mission objectives.
  2. Partial loss of mission objectives.
  3. Loss of redundancy.
  4. Reconfiguration of equipment.
  5. Potential loss of life.
- f. Potential redundancies, workarounds, or other compensation.

The FMEA methodology involves the direct participation of the designer as well as that of reliability engineers. Unfortunately, the results of the analysis often cannot be used or interpreted by people other than the analysts who perform it. In addition, the FMEA is often too fragmented, inappropriately timed (e.g., the analysis is performed after the fact to fulfill requirements rather than as a driver of the design), or is not properly disseminated or utilized by the organizations that could most benefit from it.



#### 4.4.3 Part Screening

Component and item burn-in is an economical means of screening items to help improve reliability. The burn-in tests are specialized for various components (integrated circuits, transistors and diodes, resistors and capacitors, relays, lamps, etc.) and performed to strict test criteria. These tests are done during the later stages of FSD to allow for qualification of parts and suppliers to support overall reliability effectiveness.

#### 4.4.4 Reliability and Maintainability Analyses

During the FSD phase of the design process, reliability and maintainability (R&M) analyses, which support the design and product assurance activities, shift to evaluating the design to determine if it in fact will support the various R&M allocations made in the specifications. The analyses and calculations (mean time between failures (MTBF), mean time to repair (MTTR), maximum man-hours to repair (MMHmax), etc.) all increase in fidelity as more and more detailed information about the design becomes available in FSD. Allocations of reliability and maintainability requirements down to the LRU level are identified, and predictions for the LRUs as designed, as well as analyses relating to the trade studies and reliability and maintainability problems and concerns, are reported in reliability allocations, assessments, and analysis (RAAA) and maintainability allocations, assessments and analysis (MAAA) reports.

Data collection and reporting become a large portion of the R&M task to support design assurance during FSD. The collection of data about failures experienced by FSD items forms the basis of the design assurance activities. The failure data are collected, collated, and summarized. The data are collectively analyzed and evaluated to detect and isolate real or potential reliability problems. Identified problems are actively monitored and tracked until they are resolved. They are summarized in reliability failure summary and analysis reports.

### 4.5 PACKAGING DESIGN

Physical design of the LRU often begins during its preliminary design and continues throughout the FSD phase (Figure 20). The design effort is based on a system packaging concept developed during systems engineering and the detailed circuit design data developed in the detailed circuit design task. Packaging design consists of two major tasks, mechanical hardware design and electronics packaging. Mechanical hardware design (Figure 20) includes designs of (1) system hardware, envelope, panels, racks, etc.; (2) LRU hardware, envelope, board guides, handles, etc.; (3) board hardware, size, shape, extractors, stiffeners, etc.; and (4) component hardware, heat sinks, special mounting fixtures, special packages, etc. Much of the mechanical hardware design, such as the design handles, does not depend on the circuit characteristics and is normally accomplished in parallel with the detailed circuit design effort. The design of the electronics packaging involves (1) partitioning and allocation of system, LRU, board, and component electronics (magnetics, hybrids, ASICs); (2) cabling design of system and LRUs; and (3) board and component wiring (magnetics, hybrids, ASICs).

The physical design of the hardware and electronics (Figure 21) is based on the results of extensive trade studies and an analysis of packaging alternatives. The packaging design definition includes (1) size, weight, hardware, and interfaces for the system and the LRU; (2) the number of boards, board locations, component placements, critical circuits, and requirements; (3) nuclear hardness and survivability requirements; (4) a detailed parts and modules list and descriptions; and (5) the power requirements of the system, LRU, and boards.



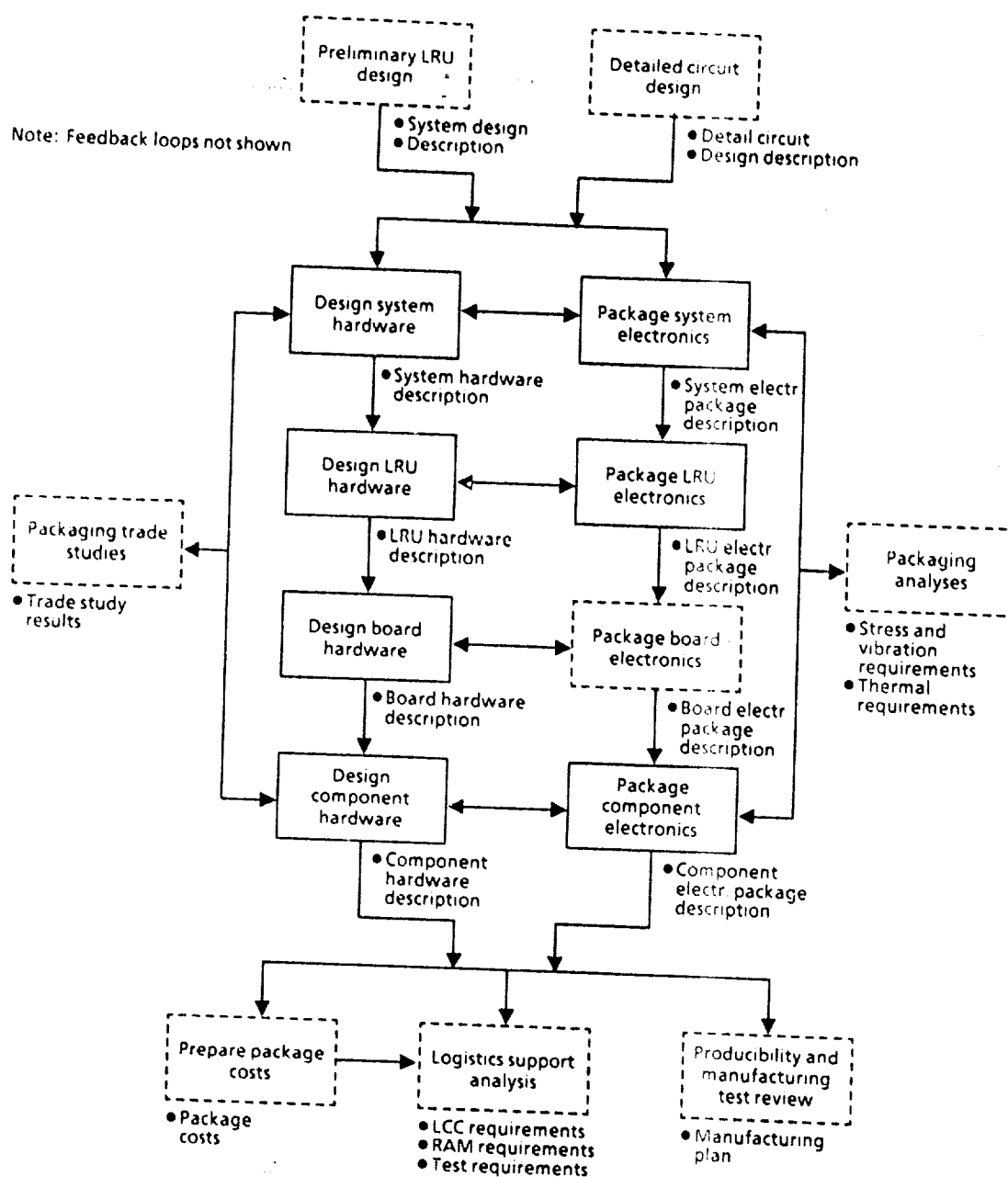


Figure 21. Detailed Packaging Design

During the preliminary LRU design, packaging design costs are estimated and sent to Logistics Support for inclusion in the system life cycle cost model. These costs typically include packaging design labor and nondeliverable items such as breadboards, mockups, and brassboards.

#### 4.5.1 Packaging Trade Studies

To support the packaging of the LRU, extensive packaging trade studies are conducted by package design specialists. Among the factors they evaluate for each packaging alternative are size, weight,

environmental control, producibility, durability, reliability, maintainability, cost, and schedule requirements. Section 5.0 provides additional details on some of the key parameter and attribute trades.

#### **4.5.2 Detailed Packaging Design**

The tasks involved in detailed packaging design are thermal control system design, packaging design of the board electronics, and design and packaging of boards.

**Thermal Control System Design.** The design of the LRU's thermal control system is initiated during systems engineering and completed during detailed design. Generally the design evolves in parallel with the mechanical and detailed circuit design of the LRU based on allocated values for cooling flow, pressure, and temperature. The baseline system concept considered during FSD usually includes a cooling system concept definition, as well as a concept for the LRU's cooling system interface. However, it is not unusual for alternative concepts to be considered during FSD, especially if design difficulties are encountered with the baseline concept or overall cooling requirements change so much that the baseline concept is no longer valid. For this reason, the cooling allocation is tracked as the design progresses to enable the thermal design to adapt to changes in the system cooling requirements.

The responsibility for the design of the thermal control system is shared between a thermal control system designer (a packaging designer) and a systems engineer. The dividing line between their responsibilities usually occurs at the envelope enclosing the LRU. The packaging designer is usually responsible for selecting the thermal management technique within this enclosure.

Among the more popular thermal control techniques for avionics systems are (1) a cold-wall technique in which the coolant is circulated through the walls of the enclosure and heat is conducted from each printed wiring board (PWB) via embedded heat conductive strips and (2) the circulation of coolant (air) directly over each PWB. This latter technique, however, has an inherent problem of contaminating the electronics with airborne particulate matter as well as liquid condensate. For space-borne applications, the enclosure envelope is much more restrictive than for airborne applications, and the enclosure design must be integrated into the vehicle's structure. The low temperature and the absence of atmosphere in space dictate the consideration and use of radiant cooling, either directly or indirectly.

**Packaging Design of the Board Electronics.** Packaging the board electronics involves partitioning the LRU electronics into boards, defining the packaging constraints, and designing the printed wiring, multiwire, stitchwire, or wirewrap boards (Figure 22). Inputs to this process are the board hardware requirements, the initial LRU partitioning, and the circuit diagrams.

Partitioning the LRU electronics into circuit boards involves the tradeoffs noted in Section 4.5.1 (see Section 5.0 for additional details). Packaging Design often assists Detailed Circuit Design (Figure 20) in allocating and defining the board partitioning by function.

Packaging constraints are derived from the circuit design constraints. Constraints are associated with decoupling capacitors, path and wire thickness, path and wire spacing, access, component placement, test points, grounding, and component types and packages.

The boards are designed from the partitioned electronics, the packaging constraints, and the board hardware design. Whether the design is a PWB or a multiwire, stitchwire, or wirewrap board depends on contractual requirements. Most applications dictate the use of PWBs for avionics. Multiwire, stitchwire, and wirewrap boards are used mainly for ground equipment and breadboarding.

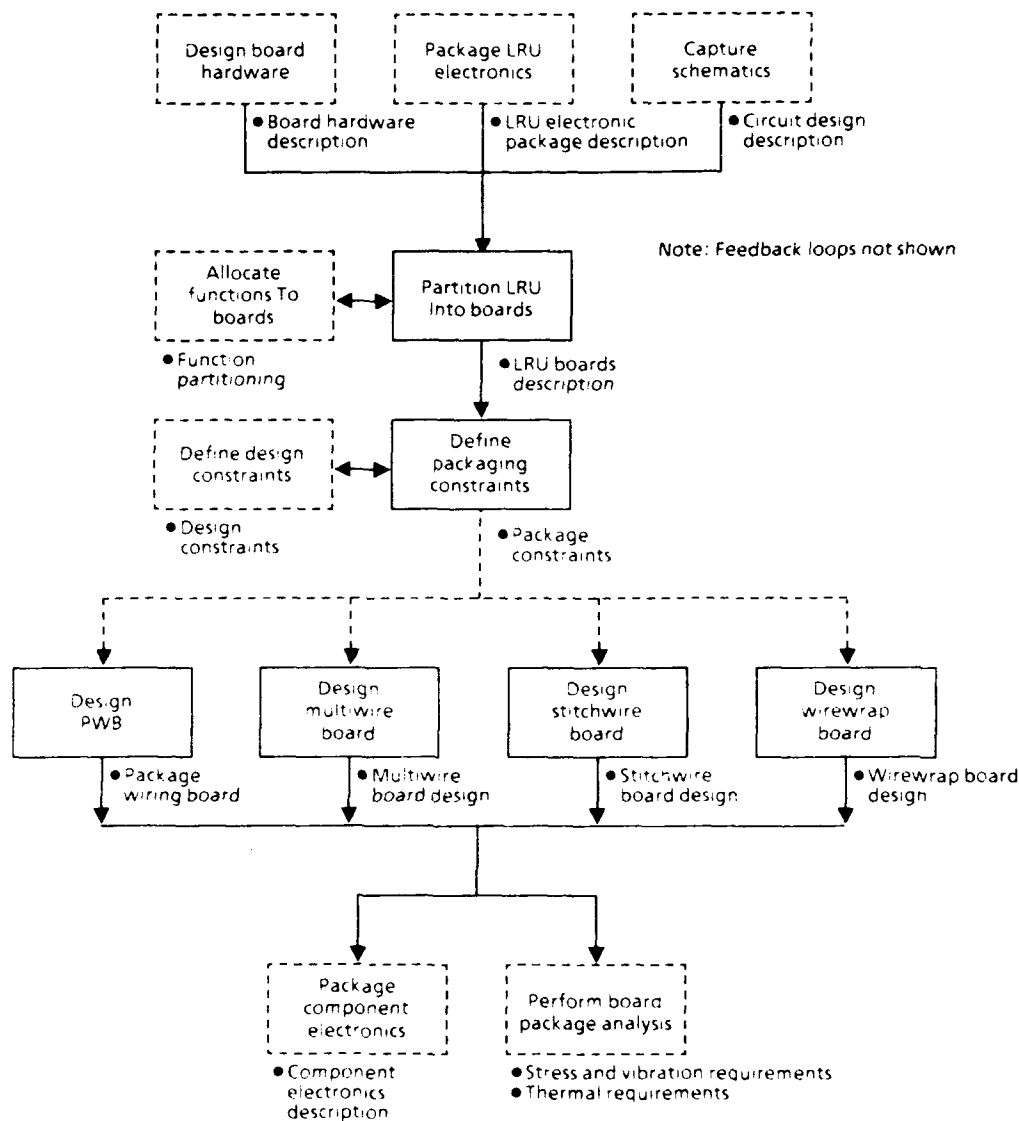


Figure 22. Package Board Electronics

**Design and Packaging of Boards.** For the most part, the design process flow is similar for PWBs and multiwire, stitchwire, and wirewrap boards (Figure 23), but the deliverables of each task are different. The following paragraphs discuss the board design process flow in general, noting only significant differences among the board design tasks.

With schematics of a partitioned board's circuit and the board and component geometric libraries as inputs, the components are placed on the board and the component connections are routed and wired, taking into account the packaging board constraints and analyses. Since component placement directly affects the board's thermal properties, the thermal constraints may dictate a component placement or density less than that desired or require certain routes and wires to be larger than

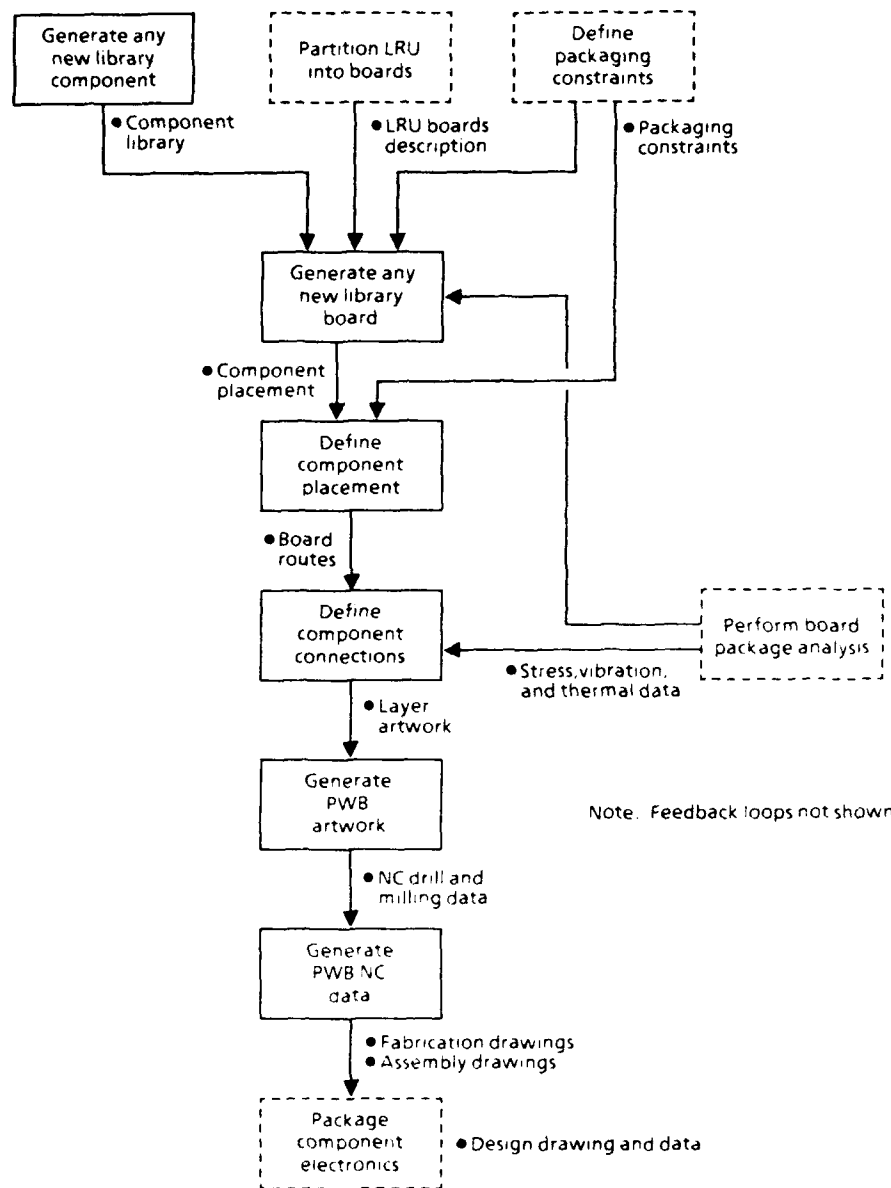


Figure 23. Design Printed Wire Board

standard or, in some cases, separated or shielded. Such considerations require a close cooperation between the circuit designer and board-package designer.

Except in a few instances, component placement and routing of avionics boards is performed manually. The experience of the Boeing packaging designers is that the automatic placement and routing tools on the market cannot adequately address the complexity of the boards typically designed for military applications.

Once component placement and routing or wiring are complete, a fabrication dataset that defines the geometry of the board layout and routing is prepared. For PWBs, masks used to etch the conductor patterns on the board are also generated. Numerical control (NC) data are generated and used to control automated manufacturing equipment that drills board holes and mills the board outline. For multiwire, stitchwire, and wirewrap boards, the NC data also control the equipment that wires the boards. Other board design outputs are assembly and fabrication drawings. The stitchwire and wirewrap board design process also generates wire books and shop lists. These outputs are all released to the engineering release unit by the program.

#### **4.5.3 Packaging Analysis**

As the packaged design evolves, it is analyzed for stress and vibration, weight, mass properties, and thermal characteristics. Detailed analyses generally begin at the component level and eventually include more of the design (board, LRU) until the critical parts of the system are analyzed. Often the analyses focus on a particular concern identified by a packaging design trade study.

The stress and vibration analysis includes nonoperating and operating environments. Nonoperating-environment analysis items are static (constant) acceleration, pressure, random vibration, and bench handling shock. Operating-environment analysis items are static acceleration, pressure, random vibration, and mission shock (missile ejection, flight buffeting). Stress and vibration analysis is conducted using computer-aided finite element programs to perform modal, transmissibility, stress, and deflection analyses. Other analytic techniques are manual calculations that use standard stress and strain relations and material properties extracted from design manuals. Some of the analyses may require tests using physical prototypes.

The thermal analysis includes steady state, transient, and worst case analyses at the system, LRU, board, and component levels. Computer-aided finite element programs are normally used to provide the thermal data needed to assess the unit's conduction, convection, and radiation thermal flow effectiveness. Other analysis techniques are manual calculations using standard thermal relations and material properties from design manuals. Thermal optimization and trade studies are performed if schedule and budget allow.

#### **4.6 MANUFACTURING DESIGN**

Manufacturing decisions often have unanticipated effects on the characteristics of an electronic circuit. For example, the manufacturing process used to solder components can affect the reliability of a circuit if quality control of the soldering process cannot be maintained. For this and other reasons, detailed producibility and manufacturing test reviews are often conducted by the Manufacturing Engineering organization within Boeing (Figure 24). The purpose of these reviews is twofold: (1) determining whether changes to the design are warranted to address producibility and testability concerns and (2) ensuring that manufacturing decisions are consistent with the objectives and requirements of the item being manufactured.

Although Manufacturing's emphasis during these reviews is on cost and schedule issues, quality control issues associated with a particular design are also evaluated. Design changes may be proposed to either the electronics (e.g., circuit elements, circuit boards) or the mechanical design of the LRU (e.g., cabinets, mounting brackets) if warranted. Although it seldom happens, significant design changes or a redesign may be recommended if Manufacturing believes the deficiencies are severe enough. Except where changes are needed for safety or airworthiness or to address design deficiencies that prevent the unit from being manufactured, all proposed changes must be justified on a cost basis.

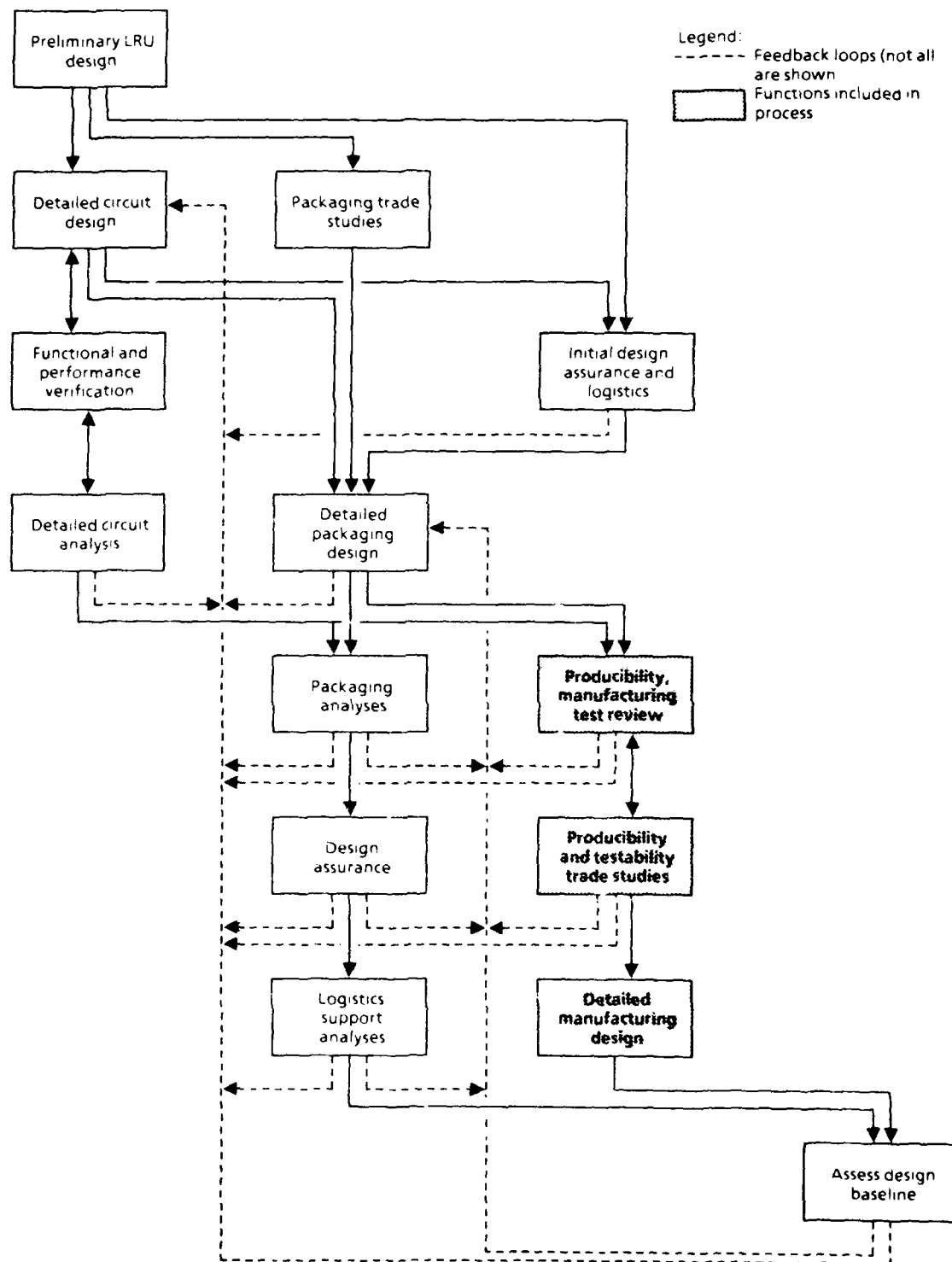


Figure 24. Manufacturing Design



During this period, Manufacturing also performs extensive producibility trade studies to determine the most cost-effective method of producing the design. Again, changes to the design may be proposed to improve the manufacturing process (e.g., enable the use of automated equipment) if the change can be justified on a cost basis. Component changes are typically suggested if an equivalent part exists that costs less, enables the use of automated assembly equipment, or is more available. Changes to the placement of components or boards are proposed if the existing placement prevents assembly or manufacturing test operations.

Although Manufacturing Design conducts the analysis and recommends changes to the design, the changes must be implemented by either Detailed Circuit Design or Packaging Design. The producibility review is an established and formal procedure within Boeing; a review of testability by the Manufacturing organization is not.

As noted, Manufacturing can only suggest changes, not require them. This appears to be partially the result of some reluctance on the part of the circuit designers and packaging designers to incorporate features in the design that affect producibility or facilitate the manufacturing test processes. In practice, operational and performance issues always take precedence over any factors arising from producibility or manufacturing test concerns.

#### **4.6.1 Producibility Review and Trade Studies**

Using an internally developed set of producibility guidelines, Manufacturing Design reviews the packaging description and part lists developed by Packaging Design. The results of this review are provided to the detailed circuit design process, the detailed packaging design process, and logistics analysis (if affected) in an iterative fashion until the producibility concerns are resolved.

Manufacturing Engineering reviews the design mainly to reduce production costs, develop manufacturing schedules, verify producibility, and verify that adequate quality control capabilities exist. Changes that affect reliability, maintainability, or testability may be proposed, however. For example, assembly methods (i.e., hand versus automated soldering and hardware mounting), component terminations (sockets versus wire terminations), tolerances, process methods (copper etching, encapsulation, etc.) can affect reliability and maintainability (accessibility, test equipment, test procedures).

Manufacturing's primary concerns in the producibility review and trade studies are ensuring that (1) the components called out in the engineering drawings are compatible with automated installation equipment and practices (e.g., axial-leaded versus edge-leaded capacitors, sufficient access for automated equipment), (2) the components are readily available (e.g., off-the-shelf components, multiple vendors, no schedule impacts), and (3) the assembly process is compatible with current manufacturing capabilities (e.g., component quality and other tolerances are not excessively tight).

#### **4.6.2 Manufacturing Test Review and Trade Studies**

Manufacturing Engineering also reviews the detailed circuit design from Detailed Circuit Design and the packaging description and parts list from Detailed Packaging Design for manufacturing test capabilities (Figure 24). This process is less formal than the producibility review and is initiated at the discretion of Detailed Circuit Design management.

There are differences in the testability requirements needed to support manufacturing and operational (in-the-field) testing. Manufacturing emphasizes a unit's functionality for quality control. Operational testing is biased toward rapid fault isolation. Since designing the unit for testability is usually the responsibility of the LRU circuit designers, and the design of the test equipment is the responsibility of an organization that designs special test equipment (STE), inconsistencies in the testability approaches often occur. As noted previously, there is some reluctance on the part of the

circuit design and packaging communities to incorporate test capabilities that address only manufacturing test and quality control issues.

#### **4.6.3 Detailed Manufacturing Design**

A key deliverable of the detailed manufacturing design task is a comprehensive manufacturing plan that details how and where hardware items will be manufactured. It defines the use of automation, specific manufacturing processes, required skills, make or buy decisions, quality assurance requirements, and other capabilities required to meet contract specifications. An overall detailed manufacturing schedule for the program is also developed at this time in negotiations with the Circuit Design and Packaging Design organizations. Baseline manufacturing, engineering, and material flows are developed from hardware descriptions developed in Detailed Circuit Design and Detailed Packaging Design. The plan is used by all the Manufacturing build and test operations to describe how all manufacturing operations will be managed to build and test the product.

Resource (e.g., skills, equipment, material, facilities) and cost (e.g., labor, equipment, materials) inputs to the plan come from all Manufacturing operations. System-level requirements, management guidelines, and the packaging description and part lists from the Packaging Design organization are used by the Detailed Manufacturing Design organization to develop the plan.

Changes to either the electronics or the hardware may be recommended as a result of the manufacturing process or scheduling conflicts. Chronologically, these changes are recommended after those resulting from the producibility and testability review, since those tasks are often completed before the detailed plan is developed and the problems are recognized. Typical changes are caused by the unavailability of qualified components or manufacturing resources.

**Detailed Manufacturing Plan.** To support the development of a plan for the manufacturing process, trade studies are conducted to assess the manufacturing alternatives. These studies typically consider:

- a. Manufacturing equipment and facility requirements (total workforce, skills, capital equipment, space, and shop load).
- b. Tooling resources and costs.
- c. Factory resources and costs.
- d. Component and material requirements and costs.
- e. Qualification of the manufacturing process.

**Unit Fabrication and Verification.** Once the designed unit is actually fabricated, no major changes can be made without a redesign. As a result, only minor tuning of the unit's packaging or fabrication process is allowed.

Changes to the design or the fabrication process are made according to the same criteria as the producibility and testability review. Where accepted, the changes result in revisions to the detailed design definition and/or the manufacturing plan.

Using the developed test software, procedures, and equipment, the FSD "as-built" unit is evaluated to ensure that it meets the design drawing requirements and contractual requirements. Process

verification tests to verify processes, functional tests to verify operation, and qualification tests to verify the "-ility" requirements are performed on the as-built unit.

**Manufacture Production Unit.** Once the FSD unit is qualified, the manufacturing dataset and plans become the definition and manufacturing process for the production (deliverable) units. At this point, changes cannot be effected without a large impact on the program's schedule and cost. As a consequence, changes are considered only if they are required by severe deficiencies in the design.

#### 4.7 LOGISTICS SUPPORT ANALYSES

During the systems engineering process (Section 3.0), the logistics support analyses (LSA) defined in MIL-STD-1388 (-1A and -2A) are initiated to aid in the development of supportability design requirements and guidelines, provide inputs to the life cycle cost analysis, and identify supportability drivers (design factors dictating the supportability of a system). These analyses are continued during detailed design primarily to support the development of technical data (e.g., technical manuals), detailed maintenance and spares requirements, and supporting equipment (e.g., special test equipment) needed to field the system of which the LRU is a part. The analyses do, however, provide a basis for assessing the supportability of the end item's design.

Ideally, the detailed design of the LRU is monitored as it evolves and these analyses are continually performed to ensure that the supportability costs are being minimized. This is not always possible, however, due to schedule, manning, or budget limitations. In many cases, supportability is assessed in depth only after the completion of the detailed packaging design task (Figure 25), often just prior to the PDR. At this point a large portion of the LRU design has been finalized and changes to the design are expensive. As a consequence, recommended design changes stemming from these analyses are incorporated into the LRU's design only if a severe deficiency is identified.

Although all 15 LSA tasks are performed during detailed design, their emphasis shifts from trying to influence the design to defining how the system being designed will be supported. Three tasks (repair-level analysis, supportability analysis, and logistics support analysis record) are considered to consume a majority of the resources allocated to the LSA. Figure 26 shows the relationship between these tasks. Figure 27 shows the relationship between availability and the key reliability, maintainability, and supportability parameters.

Repair-level analysis provides an economic basis for determining whether electronic assemblies (e.g., LRU, SRU) that have failed in the field should be discarded, repaired at an intermediate-level facility, or repaired at a depot-level facility. Among the factors this analysis considers are the unit cost of the LRU or SRU, the average number of operating hours per month, the number of man-hours required to remove and replace the unit, support equipment factors, and mean time between maintenance. Although this analysis is performed during systems engineering to influence the design, in detailed design its primary purpose is to determine the repair levels of the system specified in the configuration item specification.

Detailed system maintenance and support plans are normally developed during the late demonstration and validation or early FSD phase of design as part of the supportability task. To support this effort, the LSA study is updated to provide an improved basis for all system utilization models. During this study, the mission profile, storage requirements, maintenance philosophies, and life cycle costs are reviewed to determine how any changes in these parameters have affected supportability. Failure rate data, based on a MIL-STD-217 analysis, are used to update the organizational level maintenance predictions (e.g., maintenance man-hours).

The LSA data are documented in the logistics support analysis record (LSAR). The LSAR forms the basis for most support activities during the production and postproduction phases. Included in the LSAR is information to support technical manual development, training course identification and

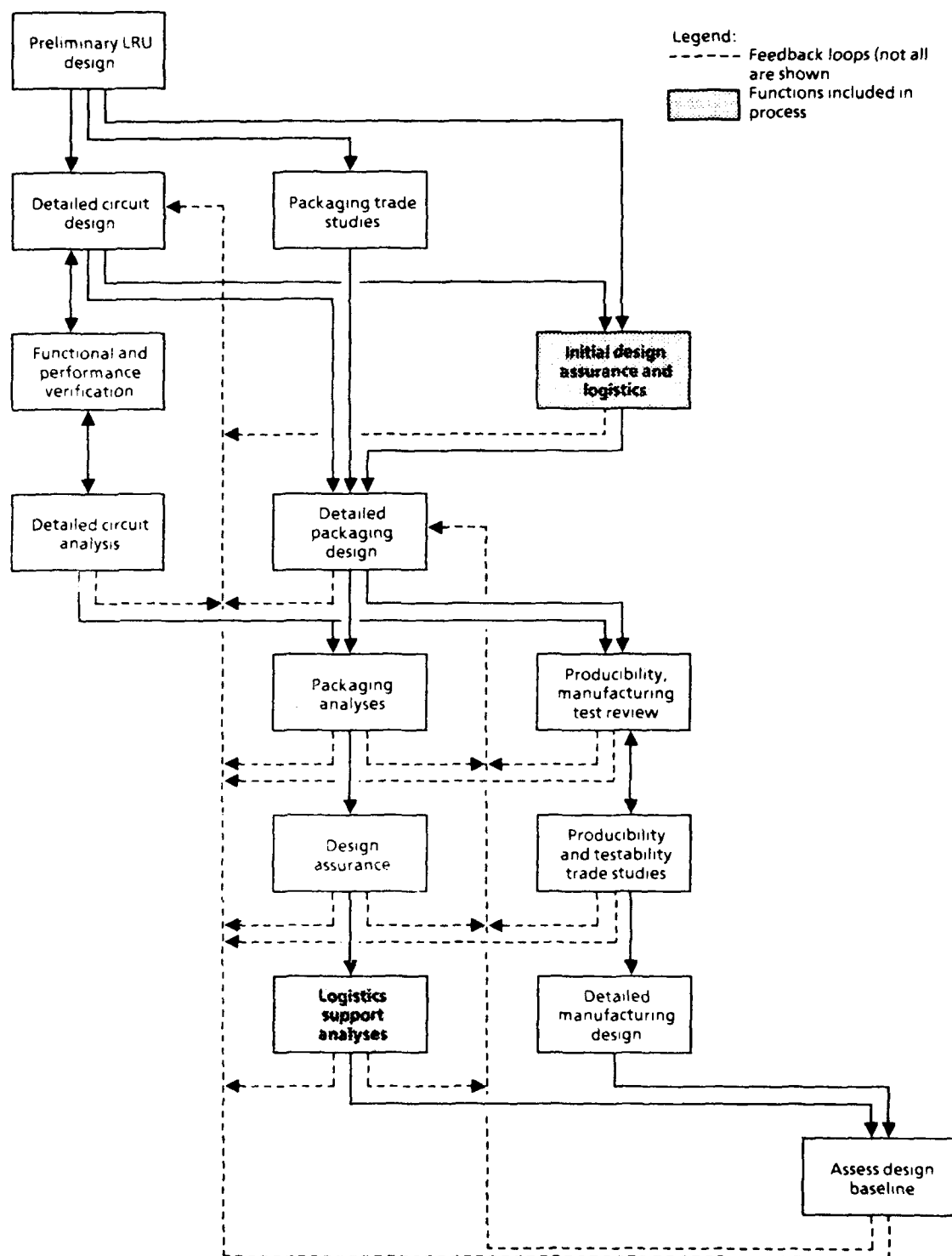


Figure 25. Logistics Support Analysis

development, training and support equipment identification, and analyses such as repair-level analyses and maintenance manning plans.

Although development of the LSAR begins as early as possible during concept exploration, the major part of this task is performed only when the system design is fairly well established. The data in the LSARs relate to operational and maintenance requirements, mission profiles, operating environments, system specification and requirements data, reliability and maintainability data, FMEA, failure criticality data, maintenance task summaries and predictions, personnel and support equipment requirements, training and technical data requirements, test procedures, facilities requirements and utilization plans, personnel skill levels, support items (tools, chairs, testers, etc.), transportability information, and handling instructions.

Within Boeing, an LSAR computer program modeled on the Automated Logistics Support Analysis (ALSA) system is used to automate parts of the MIL-STD-1388-2A LSAR.

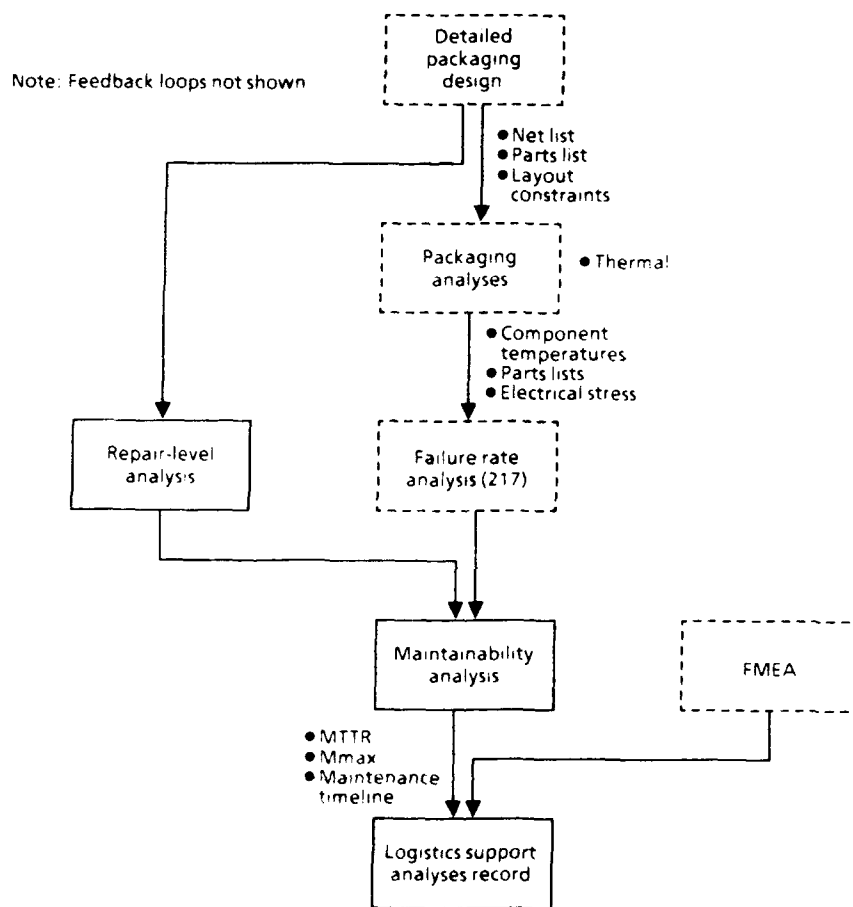


Figure 26. Logistics

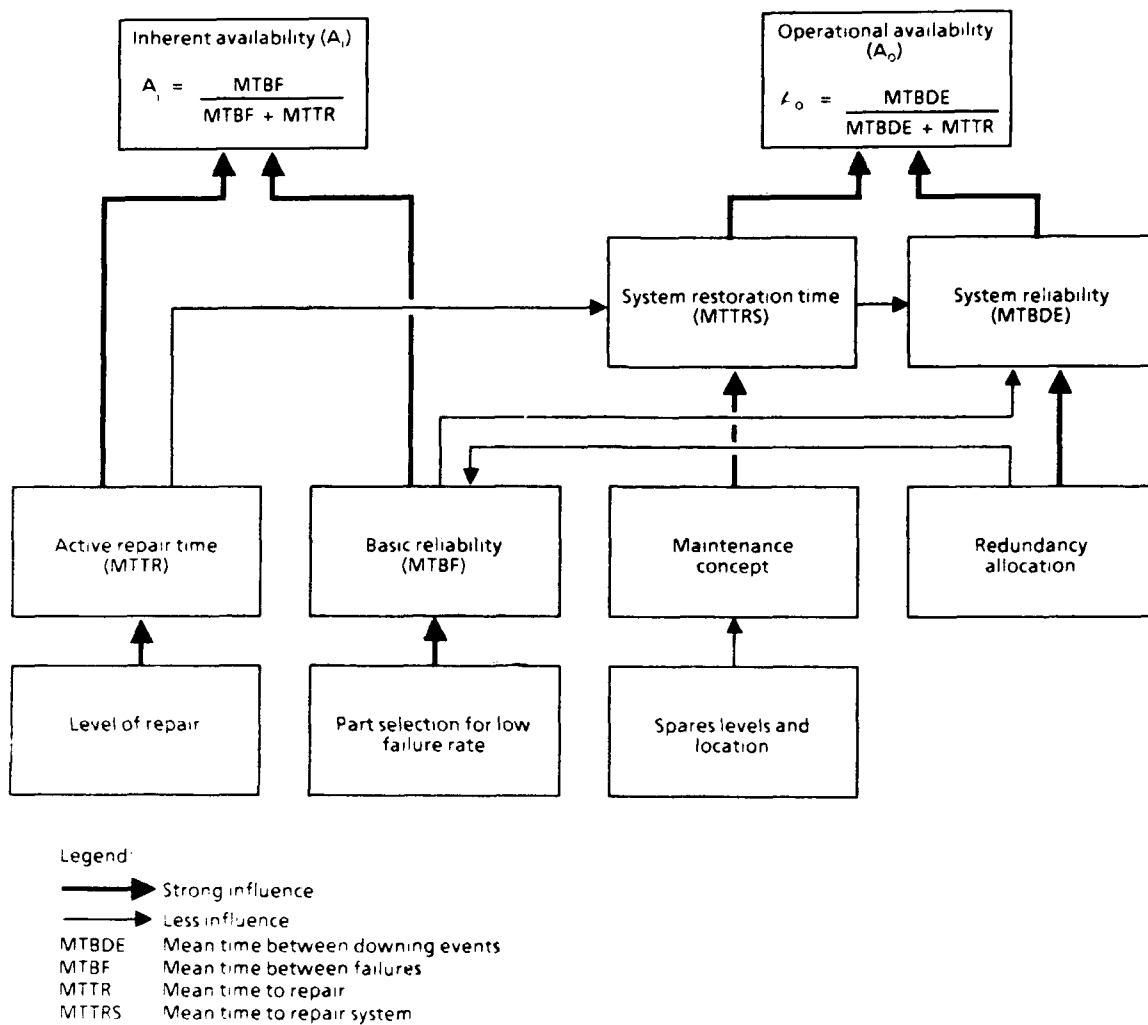


Figure 27. Reliability, Availability, and Maintainability Dependency Tree

## 5.0 DESIGN CONSIDERATIONS

It is easy to assume that the design of an electronic assembly is limited to the definition of the circuit. In fact, there are extensive physical considerations involved in such a design. Although these are largely in the domain of packaging, they influence the design from the beginning. Examples of some of these factors are noted in the following sections.

### 5.1 COMPONENT CONSIDERATIONS

**Component Technology.** Technology alternatives (e.g., CMOS, ECL, TTL, analog, hybrid) differ in design characteristics such as cost, power consumption, speed, heat generation, size (area and height), and thermal sensitivity. For avionics applications, these and other factors, such as electromagnetic interference (EMI), electromagnetic pulse (EMP), and radiation hardness, must be considered to ensure that the most appropriate technology is selected. For example, CMOS has low power requirements, a desirable characteristic for avionics applications, but is very susceptible to static electricity. If it is to be used, all interfaces to the CMOS circuitry must be buffered by embedding it within another technology or adding additional circuitry to filter all external signals. TTL is faster and consumes less area than CMOS, but consumes more power.

**Component Package Types.** For a given technology, several packaging and mounting options are typically available, such as dual inline packaging, flat pack, chip carrier, and surface mount (SMT). In addition to the obvious considerations of cost and area consumption, reliability and maintainability are also factors. DIP packages are preferred because of lower cost and ease of installation (autoinsertion), and they are generally more available. However, height and lateral space requirements (volume) may require the use of SMT. This in turn effectively eliminates the possibility of component replacement as a repair option and increases fabrication costs. In addition, if testability is a consideration, test pads should be used to facilitate autotest or technician access.

**Component Placement.** Boards may be designed to have components on one side or both. A minimum component clearance is required for use of autoinsertion and component level autotest equipment. A board real-estate check may show that the board density is too high for placement, routing, producibility, cooling, or testability requirements if only one side is used. Mounting components on both sides may be preferred in this case because more components can be placed within the same volume, but such boards are harder to design and manufacture. Mounting components on both sides of the board may require special manufacturing test rigs to support manufacturing quality assurance testing.

The different electronic components installed on a printed wiring board (PWB) possess different thermal reliability characteristics and a placement configuration for the components must be found that minimizes the failure rate of the PWB assembly and considers the electrical characteristics of the components. Board flexing also complicates component placement and routing since components should not be placed over board flex points and cannot be placed over ribs or braces.

**Connectors.** Connectors are one of the worst reliability problems. Special connectors, special handling for disassembly, or special installation are often required.

### 5.2 BOARD CONSIDERATIONS

**Board Material.** If at all possible, it is preferred to build the circuit boards of lightweight material. This may not be feasible, however, because the extra bracing or increased thickness required to minimize board flexing and vibration may consume more volume than is available.

**Board Types.** Special board types such as those having metal cores may be required to dissipate heat. These boards typically impact cost, producibility, and other issues and, therefore, are avoided if at all possible.

**Board Size.** Key concerns are whether the board size is sufficient to mount all the components allocated to it, whether the board size can be handled by all manufacturing processes, how many layers are required, and whether the line replaceable unit (LRU) enclosure requires the components to lie flat.

**Board Structure.** Shock and vibration requirements often require that the circuit board be ribbed, braced, or otherwise protected. Such features affect volume consumption and component placement. The unit must be able to withstand constant acceleration, pressure, random vibration, bench handling shock, and mission shock.

**Board Environmental Control.** Salt spray, acid, water, and humidity may cause circuit degradation and loss of signal path continuity due to corrosion or fungus. The board may need to be sealed (e.g., with conformal coating) or made of corrosion-resistant materials to improve reliability. This protection drives up fabrication cost, since a sealed unit is expensive to build, and maintenance cost, since access to the components is restricted, but it may be required to meet the reliability specification.

### 5.3 LRU CONSIDERATIONS

**LRU Size and Shape.** The LRU must be large enough to handle all the parts. For example, the board components may be too tall for the board to fit inside the LRU envelope. Laying the components flat takes up more space and may affect thermal requirements. Low-profile components may solve this problem but may be less reliable.

A special shape may be required. Special shapes dictate material type and typically drive up fabrication costs. Unusual shapes may also require special support equipment.

**LRU Weight, Center of Gravity, and Moment of Inertia** The weight of the LRU is a function of the weight of the components, boards, connectors, and LRU enclosure. The weight, shape, size, or structural characteristics of the design may result in an LRU greater than the desired maximum weight of 40 lb or in center-of-gravity problems. Ballast (additional weight) may be required to balance the LRU for technician handling.

**LRU Structure.** The LRU must be designed to withstand a variety of shocks (handling and mission), vibration, pressure differentials, and acceleration requirements. The mechanical design of the LRU may need to incorporate ribs, bracing, or other structural features.

**LRU Environmental Control.** Environmental concerns other than heat dissipation (e.g., dust and air quality), may require sealing of the LRU or the incorporation of filters.

Latitude in the design of thermal management for avionics equipment is more dependent on the air vehicle and the inherent thermal environment than on the avionics equipment. A common scenario is the updating of avionics equipment on an existing weapon system. For these cases, the available cooling capacity has a firm limit, and the equipment must be designed to operate within that limit. Depending upon the cooling requirements of individual PWBs, they may be arranged in series, in parallel, or in any combination thereof relative to the coolant flow within the enclosure. Optimization involves selection of the coolant distribution patterns and flow rates that result in a minimum failure rate for the total enclosure. Design constraints are the allowable coolant-pressure



drop across the enclosure, allocated coolant flow rate, and maximum allowable component temperatures.

#### 5.4 COUPLING OF CONSIDERATIONS

Packaging is a primary driver in the reliability, maintainability, and supportability of a system and is inherently part of the later phases of the detailed design process. Component packaging decisions affect board-level packaging, which in turn affects the design of the LRU and the overall compliance of the system with the reliability, maintainability, and supportability (RM&S) requirements. For example, a detailed designer may select ECL technology for improved circuit performance. This decision has tradeoffs in area consumption and component packaging technology (e.g., SMT components may be precluded). If other board-level designers need to use SMT components to meet their thermal constraints (SMT components dissipate heat more effectively), system maintainability and supportability will be compromised due to multiple mounting types. ECL technology also consumes more power, which in turn generates more heat. The power and thermal tradeoffs may be system-level issues if the allocations to the lower levels did not include sufficient reserves.

This tight coupling between detailed design, packaging, RM&S characteristics, and system-level requirements necessitates a continual feedback throughout all levels of the system design. Without improved knowledge of the current state of the entire system design, design engineers may select suboptimal strategies when dealing with functional design or performance problems.

Specific classes of these design considerations are evaluated by specialized engineering disciplines. This tends to impede communication and prevent the timely propagation throughout the design community of the design constraints resulting from each design decision.

## 6.0 DESIGN PROCESS PROBLEMS

As the systems being designed have grown more complex, the design process has changed. The process and schedules require the ready availability of expert design knowledge, as well as integrated supporting computer tools and data management systems.

This study has shown that –

- a. Most descriptions of the design process contain errors.
- b. The cultures of both the customer and the contractor influence the design process.
- c. The design process and its supporting computer-aided engineering (CAE) tools have difficulties and impediments that inhibit the development of optimal designs.

### 6.1 UNAVAILABILITY OF KNOWLEDGE

As the complexity of electronic systems has increased in response to competitive pressures, the processes employed in their design and manufacture have become more specialized. The design of a "typical" system now requires specialized knowledge in areas such as functional design, application-specific integrated circuit (ASIC) design, vibration, routing, automated assembly, testability, and reliability. This requirement has introduced a need for those involved in the design effort to integrate the diverse knowledge and skills of a number of disciplines. Because our knowledge of how emerging design disciplines should interact is often incomplete, the disciplines are not always effectively integrated. As a result, systems are often produced that are less than optimal or that fail to satisfy all of the requirements to which they are being designed.

The knowledge needed by designers can be divided into four areas: design principles, design methodologies, design knowledge, and reference data. These areas, representing the way in which the designer approaches a design problem and the resources that he or she can bring to bear, are discussed in the following paragraphs.

**Design Principles.** The principles of design are usually described as abstract concepts such as "design for testability." Although each discipline employs metrics, such as fault-detection coverage, and design rules, such as "do not tie resets to ground," they seldom encompass the concerns of other disciplines.

The design rules, principles, and techniques that designers must know and follow in each of these disciplines are documented in a plethora of company design manuals, military standards, program design guidelines, parts manuals, and experience databases. Unfortunately, the availability of this information does not guarantee these sources are reviewed by the designers, or even whether or not the designers know that they exist. As a consequence, designers seldom have an in-depth knowledge of the principles and rules of good design in all disciplines.

**Design Methodologies.** Design methodologies are the methods and approaches used to design systems or subsystems. There are three main categories of methodology: (1) synthesize; (2) simulate; and (3) test, analyze, and fix. Any of these methodologies can be used to produce good designs if it is used correctly, but the first two are preferable. Currently, designers predominantly use a "test, analyze, and fix" method and few CAE tools, relying instead on breadboards and prototypes. This method involves many iterative design changes and takes a long time to implement correctly. Current design programs do not allow the time needed to optimize designs using this method. The shortage of time causes the designers to consider only the principles of design that they understand well; they do not readily consider those such as testability that are more difficult to implement.

**Design Knowledge.** Many designers find it difficult to obtain the knowledge necessary to optimize designs for considerations other than functionality. Much of that knowledge is contained in experience-based databases and documents. These experience-based data could be accessed but are buried among formal design notes and documentation and not listed in any sort of easily accessible index. As an example, in order to use three of the major experience databases available, the designer must know the military system part number. The knowledge is not accessible by nomenclature or through the engineer's workstation.

**Reference Data.** Some of the required reference data on components and design elements are not readily available. The current sources of reference data are widely scattered. The most common sources are manufacturers' reference and data books, which are often incomplete. To obtain the required data on a particular part, several separate books may need to be checked. Parts databases and experience analysis databases are also not easily available.

Much of the information needed by designers for optimization is possessed by specialists. The time of these specialists is in high demand, and sometimes they are not available to provide the assistance needed by a particular project. Present systems do not provide an effective means of storing the knowledge of these experts and passing it on to other designers.

## **6.2 DESIGN PROCESS**

In general, design tasks are divided among several distinct groups and subgroups, typically by discipline or specialty. Each group is made up of individuals who have developed design styles that appear to work. This results in distinct breaks in the design process, since the actual design methodology may vary significantly between groups. In addition, the knowledge and data necessary for creating a design are fragmented among the various groups. Several related types of problems are created by these conditions.

When design descriptions are transmitted between groups, only an "outline" of the data comes across. Most of the design characteristics and metrics stay with the group that understands the relevance of the data to the design. Knowledge about key design considerations is unavailable for use by other groups. For instance, the formal document of the Detailed Design group is the schematic, which can be broken down into a netlist and a parts list. Data relating to electromagnetic interference, testing, and layout constraints, for example, are not usually specified to layout and packaging organizations.

Transmitting the data also causes delays. Some delays can be so long that the needed information does not get to the appropriate individual in time to be useful. Communication can also be a problem when transferring design data between groups. The different groups may use different tools and have to re-enter data, or they may require data in another form, which can lead to delays and errors. Just getting the answer to a single question may require several days.

As a design evolves in a top-down approach, a direct relationship in terms of parameters and metrics between the hierarchical levels is not typically generated. The formal data consist only of block and flow diagrams and a set of requirements. Modeling and analyses rarely cross and mix the hierarchical levels. Checking is done only in a general manner to ensure that a lower level representation matches a higher level one. Another aspect of this problem is that there are few metrics established to relate multiple levels of a design. Many characteristics at the high levels lack meaningful or complete metrics. For example, few metrics exist for reliability at the concept level, and no general method exists for relating reliability characteristics between hierarchical levels.

Because system-level requirements are not reflected in metrics and characteristics that relate to the lower level design task, detailed designers cannot easily determine the relative importance of key characteristics in low-level trade studies. They can conduct sensitivity analyses only on the basis of

their requirements and trade off by maximizing or minimizing a characteristic such as reliability or cost.

Pieces from an existing design are seldom used for two key reasons. Design knowledge gained from a design project is often lost once the design is complete. Trade study data and key elements in making design decisions are not captured. Rough comparisons to existing designs are made, but a large margin for error exists. Almost all existing designs require some modification for use on a new project, and modification is difficult without the original design data. There are few standard reusable design elements and interfaces.

Trade studies performed during the design process are usually informal. There are no guidelines to determine the areas to be traded, alternatives to be traded, or how detailed the study needs to be. Once the study has been performed, there is no process for capturing the data.

Few engineers do a multilevel optimizing analysis. No accepted standard optimizing analysis procedure currently exists. In addition, some of the data needed to perform the optimization are often difficult to obtain. To be maximally useful, such a technique would also have to support optimization at various levels of abstraction simultaneously.

### **6.3 CULTURE**

The major problem associated with culture is resistance to change. Organizations of both the customer and contractor have evolved as they have for good reasons.

The customer and the contractor have built organizations to cope with the increasing complexity of weapons systems and the specialized knowledge necessary to understand the technical details. These organizations consist of procurement management and design analysis specialists.

The managers of both the customer and the contractor have spent their careers with the procurement and design systems currently in place. They feel that little change is necessary, since the processes have worked in the past, and that new processes or procedures may make things worse. "Let someone else experiment" seems to be the prevalent attitude.

Contractors have spent millions of dollars developing their present systems. They have evolved as needs have forced them to change. The company's personnel understand the way the company does business. Any change would require new investment and increased training cost.

The customer has created an organization of specialists to monitor system development and the overall procurement process. These specialists have established review procedures and imposed contractual needs for periodic reviews and analysis data deliverables. The reviews and technical meetings have become part of the way business is conducted. The contractors have built organizations to match the customer's, and specialist groups have been formed both to interface with the customer's specialists and to perform the analyses required by the contract.

Because of reluctance to change this process, contractors and customers have insisted on adding checks into the design systems to analyze and verify product compliance with the specification. These checks are similar to the manufacturing quality control procedure. They do not improve the product; they just verify that it meets minimum standards.

The development of specialists for various disciplines such as reliability, maintainability, and functional design tends to create barriers between the members of the product development organization. Such groups as Reliability, Maintainability, and Logistics are formed separately from

the design team. This separation tends to promote isolation of the specialists and break down communication.

#### 6.4 DESIGN TOOLS

At present there is no integrated computer-aided design or computer-aided engineering (CAD/CAE) tool that addresses all phases of the design process and includes even the most important of the specialized analyses. There are very few tools that address the design process at the system level. Those that are available are passive diagramming tools with no provision for capturing and analyzing the relationships between portions of the diagram. As a result, the representation they create is not useful as input to an analysis tool, nor can it serve as a starting point for tools addressing detailed design.

There are more tools available to support detailed electronic circuit design. However, most of these tools are oriented to the final detailed design; they provide little support for recording more abstract levels of the design or for refining these abstractions into detailed circuits. As a result, the tools are used more as drafting and documentation aids than as design aids. Thus, the actual design process is largely a manual, paper-and-pencil activity. It is difficult to provide useful automated assistance since the fundamental process is not occurring in an automated environment.

Even if there were tools supporting each phase of the design effort, there would remain a need for an integrated tool that could analyze designs across phases. Such a tool is necessary to provide automated assistance in tracking requirements so that a high-level requirement can be related to the aspects of the design that satisfy it, and the design requirements that constrain the design of a particular element can be identified. A similar level of integration is required in a tool to verify that a design at one level is consistent with the more abstract specification of the same design at a higher level. Finally, the level of detail is not consistent across an entire design. The description of familiar aspects is likely to be left at an abstract level, while more novel portions of the design are carried to greater detail to provide greater confidence in the proposed solutions. Thus, as design actually occurs, only a tool capable of representing a design across multiple levels of abstraction can represent the current status of the entire design.

There are complex tools available for performing some of the specialized analyses supporting the design process. These tend to automate current approaches, so they critique a design after it has been produced, rather than provide useful assistance in creating the design. They also tend to address the most analytical parameters, such as functionality, timing, and heat generation. There are few tools available to measure less analytical parameters such as the reliability, maintainability, or testability of a circuit.

Designers are usually not aware of the full range of tools available to them. Even if the designer is aware of the existence of a tool, he or she requires training to use it and to interpret the results it provides. There is rarely sufficient budget to provide training in the use of tools, and even less budget to keep the training up to date as the tools evolve or are replaced with newer, more powerful tools. Inconsistent user interfaces among the tools make it difficult to retain knowledge of how to use tools that are used infrequently. Learning and using one tool tends to interfere with the retention of training about how to use another tool.

Since the tools are not integrated, data formats are usually inconsistent from tool to tool. Because the design is being produced manually, the designer must seek out or create an electronic representation of the relevant data in order to use a tool. In all but the most fortunate instances, this will require reorganization and reformatting of existing data. Frequently manual data entry is required as well. These factors reduce the utility of the tools and feed the designer's natural resistance to change, so the tools often sit unused.

Detailed circuit designers often find modeling tools and simulation useful. These tools enable them to test a circuit design by simulating it rather than producing a breadboard version of it. However, to be useful these simulations must have detailed models of the components employed. Because producing these models is a time-consuming task, they are rarely available for the most up-to-date components. Simulation is not an option for designs containing such elements. Furthermore, the designers themselves are not sophisticated enough in using the tools to handle some of the more complex current devices, such as microprocessors. Thus, even if simulation is used to analyze detailed parts of the circuits being designed, breadboarding may still be necessary to investigate component interactions. There are few tools that support design optimization. Additional tools are needed that address performance, cost, reliability, producibility, availability, etc.

It is unlikely that the entire design will be at a single level of abstraction at any time except at formal block points. So to be maximally useful, an optimization tool must support optimization of a design represented at varying levels of abstraction.

## **6.5 HISTORICAL EMPHASIS ON ANALYSIS**

Historically, emphasis has been on fixing a design after an attempt has been made at its implementation; i.e., designers have historically used a "test, analyze, and fix" methodology. The emphasis on analyzing for noncompliance with requirements after an initial attempt at the design has been made, is one of the major factors leading to the less-than-optimal systems that have been produced. In the "test, analyze, and fix" methodology, effort goes into checking to determine whether a design has met the requirements rather than designing it to optimally meet the specifications.

The basic process causes the bulk of analyses to be performed after a design has been completed. By that time, it is too late to make anything but patches. Some analyses are performed only to meet requirements, because it is too late for their results to have any effect on the design. In many cases, as more problems are found in designs, more postdesign analyses are added, rather than changing the design process to eliminate the problems.

## **6.6 DESIGN DATA MANAGEMENT**

Present design systems do not facilitate management of design data. There are no adequate tools available to manage the data as the design progresses or to ensure the validity of data already collected and being collected. Effective data management would require a common definition of the characteristics and data elements of the artifact being designed.

The various analysis specialists all need information from the design engineers and other specialists as the design progresses in order to monitor design quality. Each specialist needs to know when the design has changed and if the changes void a previous analysis.

The automated tools available today do not adequately support the concept of concurrent design. They do not provide tools for ensuring adequate interfacing between components being designed simultaneously or checking to ensure that constraints affecting other processes are not violated. Also, there are no tools available that will automatically compare and validate a design against its requirements.

As the design is decomposed from one hierarchical level to the next, requirements for each module at a level are manually developed from the requirements of the higher level. This process can often result incomplete, vague, and inconsistent requirements.

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## LIST OF ACRONYMS

AC	alternating current
AFB	Air Force base
AFSC	Air Force Systems Command
ALSA	Automated Logistics Support Analysis
AMAP	Automated Maintainability Analysis Program (S/W)
AP	array processor
ASD	Aeronautical Systems Division
ASIC	application-specific integrated circuit
ATC	Advanced Technology Center
ATE	automated test equipment
AWARE	Avionics Workstation Automated Reliability Estimator (S/W)
BIT	built-in test
BITE	built-in test equipment
C/O	checkout
CAD	computer-aided design
CAE	computer-aided engineering
CARMA	Computer-Aided Reliability Modeling Analysis (S/W)
CD/V	concept development and validation
CDR	critical design review
CDRL	contract data requirements list
CE/D	concept exploration and definition
CEPFRA	Computerized Evaluation Program for Reliability/Availability (S/W)
CEQ	Council on Environment Quality
CHEAP	Cost Effectiveness Analysis Program (S/W)
CI	configuration item
CMOS	complementary metal oxide semiconductor
D/V	development and validation
DBMS	data base management system
DC	direct current
DFT	design for testability
DI	data item
DID	data item description
DIP	dual inline package
DOD	Department of Defense
DR&P	design rules and practices
DTC	design to cost
DT&E	development test and evaluation
ECAD	electronic computer-aided design
ECAE	electronic computer-aided engineering
ECC	error checking and correction
ECL	emitter-coupled logic
EIS	environmental impact statement
EMI	electromagnetic interference
EMP	electromagnetic pulse
ERU	engineering release unit
ESCAE	Electronic Systems Computer-Aided Engineering (organization)
ESIC	ejector/stores interface unit



## LIST OF ACRONYMS (continued)

FBD	functional block diagram
FCA	functional configuration audit
FD	fault detection
FFD	functional flow diagram
FH	flight hour
FI	fault isolation
FMA	failure modes analysis
FMEA	failure mode and effects analysis
FMECA	failure mode and effects criticality analysis
FOT&E	follow-on test and evaluation
FRACAS	Failure Reporting, Analysis, and Corrective Action System
FRS	fault response sheet
FSD	full-scale development
FTA	fault tree analysis
 GIDEP	 Government-Industry Data Exchange Program
 HCI	 human-computer interface
HIRD	hardware implementation requirements document
HITS	hierarchical integrated test simulator
 I&C/O	 installation and checkout
I/O	input/output
IC	integrated circuit
ICBM	intercontinental ballistic missile
ICD	interface control document
IDD	interface definition document
ILS	integrated logistics support
IMS	information management system
IOT&E	initial operational test and evaluation
IR&D	independent research and development
 LCC	 life cycle cost
LCD	liquid crystal display
LED	light-emitting diode
LRU	line-replaceable unit
LSA	logistics support analysis
LSAR	logistics support analysis record
 MAAA	 maintainability allocations, assessments, and analysis
MCSP	mission completion success probability
Mct	corrective maintenance
Mctmax	maximum corrective maintenance
MDT	mean down time
MEAP	Maintainability Effectiveness Analysis Program
MH	manhours
MIL-STD	military standard
MIT	Massachusetts Institute of Technology
Mmax	maximum maintenance
MMH	maximum maintenance manhours
MODAS	Management Operational Data Access System
MR&D	manufacturing research and development

## LIST OF ACRONYMS (continued)

MTBDE	mean time between downing events
MTBF	mean time between failures
MTTCF	mean time to critical failure
MTTR	mean time to repair
MTTRS	mean time to restore system
NASA	National Aeronautics and Space Administration
NC	numerical control
NEPA	National Environment Policy Act
Nuc	nuclear
PD	power dissipation
PAL	programmable array logic
PC	personal computer
PCA	physical configuration audit
PDP	program development plan
PDR	preliminary design review
PgmDR	program design review
POD	point of departure
PPL	preferred parts list
PRICE	Programmed Review of Information for Costing and Evaluation
PRR	production readiness review
PWB	printed wiring board
QA	quality assurance
QC	quality control
R&M	reliability and maintainability
RAAA	reliability allocations, assessments, and analysis
RAM	reliability, availability, and maintainability
RAMCAD	Reliability, Availability, and Maintainability in Computer-Aided Design
RCA	Radio Corporation of America
RDT	reliability demonstration test
REAP	Reliability Effectiveness Analysis Program
RelCalc	Reliability Prediction Program
RF	radio frequency
RFP	request for proposal
RM&S	reliability, maintainability, and supportability
ROM	read-only memory
S/W	software
SCD	specification control drawing
SDR	system design review
SIRD	software implementation requirements document
SMT	surface mount
SOW	statement of work
SR	status review
SRAM	Short-Range Attack Missile
SRR	system requirements review
SRU	shop-replaceable unit
STE	special test equipment

**LIST OF ACRONYMS (concluded)**

STROP	Single-Thread Reliability Optimization Program (S/W)
TBD	to be determined
THERMAL	Thermal Effectiveness Analysis Program (S/W)
TPM	technical performance measurement
TR	technical review
TRD	technical requirements document
TTL	through transmission laser
ULCE	Unified Life-Cycle Engineering
VLSI	very-large-scale-scale integration
WBS	work breakdown structure
WCA	worst case analysis
WIRS	Wiring Information Release System

## APPENDIX A: DESIGN PROCESS TASKS AND ANALYSES

### A1.0 OVERVIEW

This appendix is a sampling of the analyses and tasks used in the design of electronics. The tasks listed are a fraction of those needed to complete a design; they deal mainly with the evolution of the electronics portion of a system from concept development through detailed design. The tasks listed in section A2.0 are of a general design nature, while those in A3.0 deal primarily with electronics design.

A select subset of analyses versus their characteristics is shown in Table A-1, which lists the important characteristics of each task.

Detailed descriptions of the analyses and tasks follow Table A-1. Each description contains several sections describing the important characteristics of the task or analysis, as follows:

- **Description:** Describes the task or analysis.
- **Purpose:** Explains why and when the analysis or task may be used.
- **Tools:** Lists any known, generally available, tools that have been developed chiefly for the purpose of performing or supporting the subject task or analysis. Only those tools that perform or support a large percentage of the data creation and management needs of the subject task or analysis are listed. Because they apply in most situations, tools such as general purpose database, documentation, or spreadsheet programs are not listed.
- **Inputs:** Lists the major data needed to perform the analysis or task.
- **Outputs:** Lists the major data that the analysis or task produces.
- **Where It Fits in the Design Process:** This section is provided only where additional information, beyond that provided in the primary descriptive sections above is needed to determine the phasing or prerequisites of a task or analysis.
- **Associated Military Documents:** Where applicable, lists known military handbooks, standards, and guidelines that apply to the analysis or task.
- **Limitations, Deficiencies, Problems:** Where applicable, lists any known information in these areas.

Where there is no information under a particular heading, the heading is omitted.

TABLE A-1. Analyses Matrix

Analysis	Purpose	Design function	Tools	Inputs	Outputs
Functional decomposition	<ul style="list-style-type: none"> <li>Decompose design to lower level</li> </ul>	<ul style="list-style-type: none"> <li>Systems design</li> </ul>	<ul style="list-style-type: none"> <li>RDD 100</li> </ul>	<ul style="list-style-type: none"> <li>Mission requirements</li> <li>System requirements</li> <li>System description</li> </ul>	<ul style="list-style-type: none"> <li>Lower level system description (functional flow and functional block diagrams)</li> </ul>
Functional requirements and allocation	<ul style="list-style-type: none"> <li>Identify functional and performance requirements and allocate to system elements</li> </ul>	<ul style="list-style-type: none"> <li>Systems design</li> </ul>	<ul style="list-style-type: none"> <li>RDD 100</li> </ul>	<ul style="list-style-type: none"> <li>Functional flow diagrams</li> <li>Functional requirements</li> </ul>	<ul style="list-style-type: none"> <li>System description</li> <li>Functional block diagrams</li> </ul>
Life cycle cost optimization	<ul style="list-style-type: none"> <li>Optimize system for minimum life cycle costs</li> </ul>	<ul style="list-style-type: none"> <li>Systems design</li> </ul>	<ul style="list-style-type: none"> <li>CASA</li> <li>RCA PRICE/FAST</li> </ul>	<ul style="list-style-type: none"> <li>System description</li> <li>Cost data (design manufacturing support)</li> </ul>	<ul style="list-style-type: none"> <li>Cost summaries</li> <li>Spares requirements</li> </ul>
Fault detection and fault isolation (FD/FI)	<ul style="list-style-type: none"> <li>Determine effectiveness of fault detection and fault isolation system</li> </ul>	<ul style="list-style-type: none"> <li>Systems design</li> <li>Detailed design</li> <li>Reliability and maintainability</li> </ul>	<ul style="list-style-type: none"> <li>QuickFault</li> </ul>	<ul style="list-style-type: none"> <li>Circuit description</li> <li>Test vectors (stimulus)</li> <li>Fault list</li> <li>Failure rates</li> </ul>	<ul style="list-style-type: none"> <li>Fault dictionary</li> <li>Detection list</li> <li>Detection stimulus</li> </ul>
False alarms	<ul style="list-style-type: none"> <li>Determine probability that fault detection system will report false alarms</li> </ul>	<ul style="list-style-type: none"> <li>Systems design</li> <li>Detailed design</li> <li>Reliability and maintainability</li> <li>Logistics</li> </ul>		<ul style="list-style-type: none"> <li>Circuit description</li> <li>FD / FI data</li> <li>FMA data</li> </ul>	<ul style="list-style-type: none"> <li>Fault monitor improvements</li> <li>False alarm probabilities</li> </ul>
Failure modes analyses (FMA)	<ul style="list-style-type: none"> <li>Identify failure modes</li> <li>Determine if FD/FI system is adequate</li> <li>Develop system maintenance data</li> </ul>	<ul style="list-style-type: none"> <li>Systems design</li> </ul>	<ul style="list-style-type: none"> <li>QuickFault</li> </ul>	<ul style="list-style-type: none"> <li>Circuit description</li> <li>Operation modes</li> <li>Failure modes</li> <li>Failure list</li> </ul>	<ul style="list-style-type: none"> <li>Fault monitor improvements</li> <li>Fault matrix</li> </ul>
Design constraints	<ul style="list-style-type: none"> <li>Develop design constraints applicable to each configuration item</li> </ul>	<ul style="list-style-type: none"> <li>Systems design</li> </ul>		<ul style="list-style-type: none"> <li>System requirements</li> <li>System description</li> </ul>	<ul style="list-style-type: none"> <li>Design constraints for each configuration item</li> </ul>

**TABLE A-1. Analyses Matrix (Continued)**

Analysis	Purpose	Design Function	Tools	Inputs	Outputs
Functional verification	<ul style="list-style-type: none"> <li>• Verify that design meets functional requirements</li> </ul>	<ul style="list-style-type: none"> <li>• Systems design</li> <li>• Detailed design</li> </ul>	<ul style="list-style-type: none"> <li>• QuickSim</li> <li>• MSPICE</li> <li>• SABER</li> </ul>	<ul style="list-style-type: none"> <li>• Circuit description</li> <li>• Test stimulus</li> <li>• Expected response</li> </ul>	<ul style="list-style-type: none"> <li>• Circuit outputs</li> </ul>
<ul style="list-style-type: none"> <li>• Worst case timing</li> <li>• Critical path</li> </ul>	<ul style="list-style-type: none"> <li>• Determine timing problems in circuit due to environment and critical paths in design</li> </ul>	<ul style="list-style-type: none"> <li>• Detailed design</li> </ul>		<ul style="list-style-type: none"> <li>• Circuit description</li> <li>• Operational modes</li> </ul>	<ul style="list-style-type: none"> <li>• Timing problems</li> <li>• Critical paths</li> <li>• Timing waveforms</li> </ul>
Worst case	<ul style="list-style-type: none"> <li>• Evaluate minimum and maximum voltage and current levels</li> <li>• Verify circuit performance over range</li> </ul>	<ul style="list-style-type: none"> <li>• Detailed design</li> </ul>	<ul style="list-style-type: none"> <li>• MSPICE</li> <li>• SABER</li> </ul>	<ul style="list-style-type: none"> <li>• Circuit description</li> <li>• Component information</li> <li>• Environment</li> </ul>	<ul style="list-style-type: none"> <li>• Circuit sensitivity to worst case component quality, environment, power</li> <li>• Evidence of compliance or noncompliance with specs</li> <li>• Circuit outputs</li> </ul>
Loading	<ul style="list-style-type: none"> <li>• Determine loading on device outputs to find overloaded devices</li> </ul>	<ul style="list-style-type: none"> <li>• Detailed design</li> </ul>	<ul style="list-style-type: none"> <li>• Loading Analysis</li> </ul>	<ul style="list-style-type: none"> <li>• Circuit description</li> <li>• Device specifications</li> <li>• Interface specifications</li> <li>• Derating factor</li> </ul>	<ul style="list-style-type: none"> <li>• Loading of device outputs</li> <li>• Outputs exceeding derated loading specifications</li> </ul>
Electrical stress	<ul style="list-style-type: none"> <li>• Find the power dissipation of electrical components in order to aid reliability calculations</li> </ul>	<ul style="list-style-type: none"> <li>• Detailed design</li> </ul>	<ul style="list-style-type: none"> <li>• MSPICE</li> </ul>	<ul style="list-style-type: none"> <li>• Circuit description</li> <li>• Device specifications</li> <li>• Operational modes</li> </ul>	<ul style="list-style-type: none"> <li>• Power dissipation for components</li> </ul>
Testability	<ul style="list-style-type: none"> <li>• Determine the testability of electronic circuits and recommend improvements</li> </ul>	<ul style="list-style-type: none"> <li>• Systems design</li> <li>• Detailed design</li> <li>• Manufacturing design</li> </ul>	<ul style="list-style-type: none"> <li>• T<sup>3</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Circuit description</li> <li>• Physical layout</li> <li>• Operational modes</li> </ul>	<ul style="list-style-type: none"> <li>• Testability rating</li> <li>• Testability recommendations</li> </ul>

TABLE A-1. Analyses Matrix (Continued)

Analysis	Purpose	Design Function	Tools	Inputs	Outputs
<ul style="list-style-type: none"> <li>● Failure modes effects analysis (FMEA)</li> <li>● Failure modes effects criticality analysis (FMECA)</li> </ul>	<ul style="list-style-type: none"> <li>● Determine effects of failures on system operation and rank according to severity and probability</li> </ul>	<ul style="list-style-type: none"> <li>● Reliability and maintainability</li> </ul>	<ul style="list-style-type: none"> <li>● Quick Fault</li> </ul>	<ul style="list-style-type: none"> <li>● System description</li> <li>● Block diagrams</li> <li>● Functional block diagrams</li> <li>● Failure modes</li> <li>● Mission functional and operational modes</li> <li>● Environmental profiles</li> <li>● Mission times</li> <li>● Reliability block diagrams</li> <li>● Failure rates</li> <li>● Failure effects</li> <li>● Failure severity</li> <li>● Failure rates and probability</li> <li>● Operating time</li> </ul>	<ul style="list-style-type: none"> <li>● Failure effects</li> <li>● Failure detection method</li> <li>● Compensating provisions</li> <li>● Severity classification</li> <li>● Item criticality</li> <li>● Criticality matrix</li> </ul>
Preliminary layout	<ul style="list-style-type: none"> <li>● Determine a preliminary layout to calculate reliability, testability, etc early in design to facilitate changes</li> </ul>	<ul style="list-style-type: none"> <li>● Detailed design</li> <li>● Physical design</li> </ul>	<ul style="list-style-type: none"> <li>● Board Station</li> </ul>	<ul style="list-style-type: none"> <li>● Circuit description</li> <li>● Package specifications</li> <li>● Board specifications</li> </ul>	<ul style="list-style-type: none"> <li>● Preliminary layout</li> </ul>
Thermal analysis	<ul style="list-style-type: none"> <li>● Determine component temperatures to calculate reliability</li> </ul>	<ul style="list-style-type: none"> <li>● Detailed design</li> <li>● Physical design</li> </ul>	<ul style="list-style-type: none"> <li>● Sinds</li> <li>● Therm</li> </ul>	<ul style="list-style-type: none"> <li>● Circuit description</li> <li>● Physical layout and description</li> <li>● Power dissipation</li> <li>● Board and package descriptions</li> <li>● Cooling descriptions</li> </ul>	<ul style="list-style-type: none"> <li>● Temperature of each device</li> </ul>

**TABLE A-1. Analyses Matrix (Concluded)**

Analysis	Purpose	Design Function	Tools	Inputs	Outputs
<ul style="list-style-type: none"> <li>● Reliability</li> <li>● Failure rate</li> <li>● Mean time between failures (MTBF)</li> <li>● Mean time between downing events (MTBDE)</li> </ul>	<ul style="list-style-type: none"> <li>● Predict failure rates of components and systems and mean time between failures</li> </ul>	<ul style="list-style-type: none"> <li>● Reliability and maintainability</li> </ul>	<ul style="list-style-type: none"> <li>● AWARE</li> <li>● RelCalc 2, SysCalc</li> <li>● RPP</li> <li>● CARMA</li> <li>● CEPFRA</li> <li>● STROP</li> </ul>	<ul style="list-style-type: none"> <li>● Circuit description</li> <li>● Component temperatures</li> <li>● Functional description</li> <li>● Redundancy</li> </ul>	<ul style="list-style-type: none"> <li>● Component failure rates</li> <li>● System failure rates</li> <li>● Component and system MTBF</li> <li>● Component and system MTBDE</li> </ul>
Operational availability	<ul style="list-style-type: none"> <li>● Predict operational availability of system</li> </ul>	<ul style="list-style-type: none"> <li>● Reliability and maintainability</li> </ul>	<ul style="list-style-type: none"> <li>● CEPFRA</li> <li>● MIREM</li> <li>● GRAMP</li> </ul>	<ul style="list-style-type: none"> <li>● Failure and/or repair rates</li> <li>● Initial reliability condition of system</li> <li>● Mission time</li> </ul>	<ul style="list-style-type: none"> <li>● Availability of system</li> </ul>
Mission success probability	<ul style="list-style-type: none"> <li>● Predict probability that mission can be completed</li> </ul>	<ul style="list-style-type: none"> <li>● Reliability and maintainability</li> </ul>	<ul style="list-style-type: none"> <li>● CARMA</li> <li>● MIREM</li> <li>● GRAMP</li> </ul>	<ul style="list-style-type: none"> <li>● FMEA and FMECA data</li> </ul>	<ul style="list-style-type: none"> <li>● Probability of mission success</li> </ul>
Failure report and corrective action system (FRACAS)	<ul style="list-style-type: none"> <li>● Identify actions to address reliability and maintainability problem area</li> </ul>	<ul style="list-style-type: none"> <li>● Reliability and maintainability</li> </ul>		<ul style="list-style-type: none"> <li>● System description</li> <li>● Field reliability and maintainability data</li> </ul>	<ul style="list-style-type: none"> <li>● Corrective actions required</li> </ul>
<ul style="list-style-type: none"> <li>● Maintainability timeline</li> <li>● Mean time to repair (MTTR)</li> <li>● Mmax</li> </ul>	<ul style="list-style-type: none"> <li>● Predict repair times and determine maintenance schedules</li> </ul>	<ul style="list-style-type: none"> <li>● Reliability and maintainability</li> </ul>	<ul style="list-style-type: none"> <li>● AMAP</li> <li>● GRAMP</li> </ul>	<ul style="list-style-type: none"> <li>● System description</li> <li>● FD/FI data</li> <li>● FMA data</li> <li>● MTBF and MTBDE</li> <li>● Failure rates</li> </ul>	<ul style="list-style-type: none"> <li>● MTTR</li> <li>● Mmax</li> <li>● Maintenance schedules</li> </ul>
Fault tree analysis (FTA)	<ul style="list-style-type: none"> <li>● Safety analysis to determine how failure modes could affect property, life, etc</li> </ul>	<ul style="list-style-type: none"> <li>● Logistics</li> </ul>	<ul style="list-style-type: none"> <li>● FTREE</li> <li>● SETS</li> <li>● SEP</li> </ul>	<ul style="list-style-type: none"> <li>● Fault tree logic</li> <li>● Failure rates and expose times</li> </ul>	<ul style="list-style-type: none"> <li>● Fault tree event failure probabilities</li> </ul>
Repair level	<ul style="list-style-type: none"> <li>● Determine optimum location to perform repairs or maintenance</li> </ul>	<ul style="list-style-type: none"> <li>● Logistics</li> </ul>	<ul style="list-style-type: none"> <li>● NRLA</li> </ul>	<ul style="list-style-type: none"> <li>● System description</li> <li>● FMA data</li> </ul>	<ul style="list-style-type: none"> <li>● Optimal repair time</li> </ul>



## **A2.0 SYSTEMS ENGINEERING**

Systems engineering is a set of techniques and procedures used to—

- a. Systematically develop and specify a comprehensive, structured set of functional, performance, design, and quality assurance requirements for the system or project.
- b. Define technical, cost, and effectiveness measures that can be used to manage the design, development, construction, operation, and maintenance of the system.
- c. Optimize the system by developing a configuration of subsystems that can cost-effectively produce an output.

### **A2.1 OBJECTIVES AND REQUIREMENTS**

The complete baseline mission and system objectives and requirements must be clearly, explicitly, and concisely documented before the beginning of functional analysis and development of the derived requirements and design for each program, phase, project, or task.

#### **A2.1.1 Mission Objectives and Requirements**

The primary and secondary missions the system is to accomplish must be thoroughly understood in terms of need, user requirements, specific objectives and profiles, operating environment (climatological, related systems, and threat), measurement of effectiveness, and user operational concepts and limitations.

#### **A2.1.1.1 Needs Assessment**

##### **Description**

The user's specific needs should be continually assessed by contractor study programs to guide product and technology development.

##### **Purpose**

- To maintain the contractor in a position to recognize and bid on potential new business in its area of marketing interest.
- To assist in developing successful proposal strategies and presentations.
- To relate potential customers' needs and/or functional deficiencies to the contractor's product development potential, both immediate and long range.
- To aid management in selecting and justifying new programs for startup.

##### **Tools**

- None commercially available.

##### **Inputs**

- Customer needs and wants.

##### **Outputs**

- Assessment, evaluation, and documentation leading to preliminary design and requirements.

##### **Where It Fits in the Design Process**

**Phase Application:** The needs assessment is done in or prior to the concept exploration and definition (CE/D) phase and leads to development of a proposal to perform special studies or to initiate the CE/D phase. A needs assessment may also be required for definition and/or initiation of a major system modification program. If done prior to the CE/D phase, the needs assessment may be updated at the start of the CE/D phase and become a reference for follow-on phases.

**Prerequisites:** Knowledge of the government system development process and associated sources of data is required.

### **A2.1.1.2 Program Initiation Documents**

#### **Description**

Authority to initiate a program must be documented. For programs initiated by the DOD, the acquisition decision memorandum and related documents must be obtained. For programs initiated by Boeing, authorized program scope, objectives, and customer must be explicitly defined.

#### **Purpose**

- To initiate study or development activities on a new program or program phase.
- To authorize program or proposal activities, including initial planning of program development activities by phases and participants.

#### **Tools**

- None commercially available.

#### **Inputs**

- Threat assessment.
- Description of current system shortfalls.
- Alternative solutions for shortfalls, including improvement of products in inventory.
- Risk assessment.

#### **Outputs**

- Request for equipment – to hardware or study.
- Statement of need – to hardware or study.

#### **Where It Fits in the Design Process**

**Phase Application:** The primary emphasis is on enabling a new program to start up. However, appropriate authorizing documents are also required to initiate action for each program phase.

**Prerequisites:** For contractor initiation of new programs, the prerequisite is the completion of needs assessment and product development studies. For the contractor to initiate activity on ongoing programs, participation (including customer coordination) in and/or availability of results from the mission and system definition studies of the preceding phase would be prerequisites.

### **A2.1.1.3 Mission Objectives**

#### **Description**

Mission objectives must be explicitly documented in the user's operational terms for both primary and secondary or tertiary missions to ensure that the contractor understands what the user wants the system to do. They are normally provided by the customer on government programs; however, Systems Engineering review and assessment are prerequisites to developing a contractor request for proposal (RFP) or statement of work (SOW) response. On contractor-initiated program activities, development of mission objectives by initiating the mission analysis of section A2.2.2.1 is part of the product development initiative discussed in section A2.1.2.1.

#### **Purpose**

- To define in precise and explicit user terms what the system is to do.
- To serve as necessary inputs to the mission analysis in section A2.2.2.1 and in general to all systems engineering activities discussed in sections A2.2, A2.3, A2.4, and A2.5.

#### **Tools**

- None commercially available.

#### **Inputs**

- Targets, including theaters of operations and mission definitions, for military systems
- Initial operational capability date.

#### **Outputs**

- Specific target descriptions for military weapons
- Mission profiles for military weapons.
- Employment concept for military weapons.
- Target- and munition-matching data for military weapons.

#### **Where It Fits in the Design Process**

**Phase Application:** Understanding the mission objectives is essential to all program phases. At the start of the CE/D phase, mission objectives may be defined in the form of a technical requirements document (TRD). During early program development phases, the TRD may identify minimum requirements and objectives as well as goals or desired capabilities. By the start of the full-scale development (FSD) phase, the mission objectives should be documented to specification quality and format.

**Prerequisites:** Mission area studies and needs assessment activities (see A2.1.1.1) and product development studies (see A2.1.2.1) should be performed as part of defining and refining a program's mission objectives.

#### **A2.1.1.4 Operational Environment and Requirements**

##### **Description**

The total environment in which the system is to operate must be defined: interfacing systems, threat environments, limits on self-induced environments, climatological environment, command structure, communications, operating personnel limitations, and logistics constraints. It is normally provided by the customer on government programs. However, Systems Engineering review and assessment are prerequisites to developing a contractor RFP or SOW response. On contractor-initiated program activities, this is part of the product development initiative. However, in the interests of total program efficiencies, some system-level trades may be possible or desirable during early program development phases (e.g., deployment locations restricted to eliminate undue climatic extremes; area generation of a mobile launch system used to reduce the in-place hardness required for nuclear survivability). However, these tradeable areas must be agreed to or approved by the customer.

##### **Purpose**

- To define in precise and explicit terms the total environment the system could experience.
- To serve as necessary input to the systems engineering activities discussed in sections A2.2, A2.3, A2.4, and A2.5; but they may be and should have been developed using the same interactive, iterative technique.

##### **Tools**

- None commercially available.

##### **Inputs**

- Operational employment areas (geographical).
- Operating conditions (dust, smoke, etc.).
- Mission profiles.

##### **Outputs**

- Environmental specification (for system and segment specification).

##### **Where It Fits in the Design Process**

**Phase Application:** The environmental specification is essential to all program phases. At the start of the CE/D phase, it may be in the form of a technical requirements document. During early program development phases, it may identify minimum requirements and objectives as well as goals or desired capabilities. By the start of the FSD phase, it should be of specification quality and format.

**Prerequisites:** Mission area studies and needs assessment activities (sec. A2.1.1.1) and product development studies (sec. A2.1.2.1) should be performed as part of defining and refining a program's mission objectives. In addition, locations of intended use need to be defined.

#### **A2.1.1.5 Measures of Effectiveness**

##### **Description**

System-level measures of effectiveness must be established and agreed upon with the customer for evaluation of alternative concepts and designs, establishment of system success criteria, and allocation of performance parameter budgets. Measures of effectiveness should be quantifiable, but many important ones cannot be quantified, so subjective ratings must be used in those cases.

##### **Purpose**

- To serve as a common set of standards and criteria for use in selecting a preferred solution and/or verifying its suitability. They are prerequisite to performing concept selection trade studies.

##### **Tools**

- None commercially available.

##### **Inputs**

- Mission requirements for military systems.
- Targets.
- Production requests (rate, quality) for civil systems.

##### **Outputs**

- Measures of merit for managing system development.
- Technical (performance and design) measurements.
- Cost (unit and life cycle cost) measurements.

##### **Where It Fits in the Design Process**

**Phase Application:** Measures of effectiveness are required at a mission and/or system level for the CE/D and concept demonstration and validation (CD/V) phases. They may be used at progressively lower levels to support trade studies until completion of technical design reviews (e.g., critical design reviews).

**Prerequisites:** Mission objectives, the operational environment and requirements, customer-provided requirements and system constraints and nontradeable requirements are prerequisites.

### **A2.1.1.6 Operational Concepts**

#### **Description**

The operational concepts and methods, interoperability requirements, and high-level procedures must be documented for each alternative concept evaluated. The operational concept for the system concept selected should be agreed upon with the using command. The operational concept assists system designers in identifying and allocating functions, developing human-machine interfaces, and budgeting performance allocations. It is normally provided by the customer on government programs; however, Systems Engineering review and assessment are prerequisites to developing a contractor RFP or SOW response. On contractor-initiated program activities, development of operational concepts by initiating the mission analysis of section A2.2.2.1 is part of the product development initiative discussed in section A2.1.2.1.

#### **Purpose**

- To define the user's concept of operating the system to achieve the mission objectives (sec. A2.1.1.1). Operational concepts are necessary inputs to the mission analysis in section A2.2.2.1 and in general to all system engineering activities discussed in sections A2.2, A2.3, A2.4, and A2.5.

#### **Tools**

- None commercially available.

#### **Inputs**

- Missions.
- Targets.
- Threat.
- Employment areas.

#### **Outputs**

- Wartime operating concept.
- Peacetime operating concept.
- Top-level maintenance concept.

#### **Where It Fits in the Design Process**

**Phase Application:** Operational concepts are essential to all program phases. They may be preliminary or internally postulated to support the CE/D phase and even the start of the CD/V phase. They should be provided by the customer (normally they will be prepared by the user) and accepted or agreed to by both the customer and the user by the start of or early in the FSD phase.

**Prerequisite:** Mission area studies and needs assessment activities (sec A2.1.1.1) and product development studies (sec A2.1.2.1) should be performed as part of defining and refining a program's mission objectives. In addition, the operating and support agencies or organizations should be identified.

### **A2.1.2 System Objectives and Requirements**

The initial technical objectives and requirements needed for the system to accomplish the defined missions must be thoroughly understood and documented before the requirements analysis is extended for each development cycle. The objectives and requirements include performance, availability, constraints, maintenance concepts, general verification concept, external interfaces, and the baseline concept or system configuration.

#### **A2.1.2.1 Product Development Initiative**

##### **Description**

Contractor-initiated exploration of new technologies and preliminary design studies in support of contractor marketing objectives should employ systems engineering methods and practices to develop conceptual systems and technology development roadmaps.

##### **Purpose**

- To complement the needs assessment defined in section A2.1.1.1.
- Specifically, to define how the contractor's product development capabilities can be applied to known or perceived needs of a potential customer, or where technological advances appear to have potential for creating new needs and/or customers.
- To aid management in prioritizing and selecting areas of product development and/or proposal activities.
- To define the system concept and its development approach for the mission defined in section A2.1.1.1.

##### **Tools**

- None commercially available.

##### **Inputs**

- An iterative process for developing conceptual solutions and establishing priorities for applying technological advances to areas of known or perceived needs.

##### **Outputs**

- System preliminary design definition.

##### **Where It Fits in the Design Process**

**Phase Application:** System objectives and requirements are normally defined as a lead-in to, or part of, the CE/D phase. They may be updated and refined as part of the CD/V phase and the proposal for the FSD phase. They become reference material for follow-on phases.

**Prerequisites:** Knowledge of contractor design and development capabilities and associated technology development and trends is a prerequisite. There may also be a strong influence from the contractor's marketing strategies, both current and long range.



### **A2.1.2.2 Customer-Provided Requirements**

#### **Description**

Customer-provided system requirements must be documented, thoroughly reviewed, and understood and necessary changes must be negotiated, before the requirements are made a contractual obligation. Special attention must be devoted to evaluating the suitability and cost effectiveness of secondary and tertiary requirements established by reference in primary requirements. Customer-provided requirements may result in an unsolicited proposal and/or coordination with the customer or government agencies evaluating the need for or seeking to establish a new program.

Not a contractor function.

#### **Purpose**

- To define the performance and characteristics the customer requires the system being developed to meet and demonstrate.
- To vary specific activities, conditions, or outputs of the development process.
- To serve as prerequisites to initiating contractor activities for each phase and each major systems engineering task and specifically as inputs to functional analysis.

#### **Tools**

- None commercially available.

#### **Inputs**

- SOW task items.
- Contract data requirements list (CDRL ) items.
- TRDs or equivalent.

#### **Outputs**

- Boeing requirements document, including derived requirements.

#### **Where It Fits in the Design Process**

**Phase Application:** Customer-provided requirements are applicable to all phases and should become progressively more detailed and definitive as the program progresses. For the CE/D and CD/V phases, requirements may be at a high level, be defined in parametric terms, and include goals and/or desires. As the program progresses, requirements derived or made definite during a phase may become customer provided for the next phase.

### **A2.1.2.3 System Constraints and Non-tradeable Requirements**

#### **Description**

Restraints and non-tradeable requirements must be specifically identified prior to functional analysis, performance allocation, and verification of analysis.

#### **Purpose**

- To define and agree on conditions and boundaries that limit or constrain the operation, development, and acquisition of the system.
- To similarly define and result in agreement on system constraints that are mandatory or have limits not subject to tradeoff considerations.
- Mission- and system-level constraints and non-tradeable requirements: to guide and control or bound the entire system definition process.
- Detailed design constraints: to ensure that the design of each element or configuration item meets all system-level requirements, including those from the specialties and disciplines.
- To serve as an integration tool for Systems Engineering and as a set of design requirements for the hardware and/or software designer.

#### **Tools**

- None commercially available.

#### **Inputs**

- Mission objectives.
- Any design constraints and non-tradeable requirements defined by the customer.
- System requirements.
- Design constraints.

#### **Outputs**

- Definition of constraints and non-tradeable requirements.

#### **Where It Fits in the Design Process**

**Phase Application:** A definition of system level constraints and requirements are critical for the CE/D and CD/V phases and strongly affect which alternative concepts are developed and which trade studies are performed. They should be initialized and validated through the CD/V phase and be inputs to the FSD phase. They should be preliminary and incomplete at the start of the FSD phase, with finalization as necessary to support specification development and hardware and software.

**Prerequisites:** Mission objectives and requirements (sec. A2.1.1) should be defined before the highest or first level of constraints and non-tradeable requirements is determined. For more detailed design constraints, preliminary functional analysis (sec. A2.2) and system configuration definition and requirements allocation (sec. A2.2.1.3), should have been accomplished.

## **A2.1.2.4 System External Interface Definition**

### **Description**

Interfaces external to the system being developed must be defined technically to the degree of detail appropriate for the next level of functional analysis before that level of analysis begins. "External interfaces" include those implicit in the operational environment (sec. A2.1.1.4) and operational concepts (sec. A2.1.1.6).

### **Purpose**

- To define how the system relates to and/or interacts with existing or separately developed systems, installations, equipment, or operations.
- Mission and system levels: to guide and control or bound the entire system definition process.
- To influence allocation of development responsibilities between contractors.
- Design level: to ensure physical and functional compatibility with the outside world when the system is deployed and operated in its intended environment.

### **Tools**

- None commercially available.

### **Inputs**

- Support interface control activities and meetings.
- Possibly chair interface control working group.
- Identify external functional and physical interfaces.
- Prepare listing of data required to be exchanged to progressively define and control the interfaces.

### **Outputs**

- *Interface definition and documentation.*

### **Where It Fits in the Design Process**

**Phase Application:** During early development phases (e.g., CE/D and CD/V), external interface definitions coordinate and guide the development process and ensure that it remains integrated within external developments. As the design becomes final (e.g., in the FSD and production phases), the interfaces are defined and controlled to ensure that the system will fit and function as intended in its proper niche.

**Prerequisites:** There are none for initial program startup. Interface definition is an integral part of defining mission objectives and allocating them to a system to be developed. On major programs where development is divided or allocated among contractors with varying specialties (e.g., guidance and control contractors, airframe contractors, etc.), the customer is required to establish a contract and system acquisition management plan. Detailed definition of external interfaces is an integral part of functional analysis and system design.

### **A2.1.2.5 Phase Baseline**

#### **Description**

Before further analysis and design in each iteration of a system's design, the baseline or point of departure must be documented to coordinate engineering activities, maintain configuration accounting, establish a basis for costing, assist in developing specifications, assist in identifying changes, and maintain control of changes before implementation.

#### **Purpose**

- To define and document the system baseline at the start and end of each phase and ensure an efficient transition between phases.
- To summarize and document the current development status of system requirements and system configurations.
- To coordinate and track the evolution of these requirements and configurations, with emphasis on the transition between or across phases.

#### **Tools**

- ECAD/ECAE schematic capture and documentation tools.

#### **Inputs**

- Mission objectives, system requirements, and traceability.
- System specification and specification tree.
- System description.

#### **Outputs**

- Baseline documentation.

#### **Where It Fits in the Design Process**

**Phase Application:** A phase baseline is required at the beginning and end of each phase. It is used to define, in documented and measurable terms, the point of departure for phase start and the result at phase end. The result at the end of a phase then becomes the basis for the point of departure of the next phase.

**Prerequisites:** Identifying the phase baseline requires enough previous analysis and design to establish a point of departure for the activities to be performed in the next phase or step in the development process. For the CE/D phase, mission objectives (sec. A2.1.1.3), operational environment and requirements (sec. A2.1.1.4), and operation concepts (sec. A2.1.1.6) should be established at least in preliminary form. Also, at least a preliminary definition should be available for customer-provided requirements (sec. A2.1.2.2), system constraints and non-tradeable requirements (sec. A2.1.2.3), and system external interfaces (sec. A2.1.2.4).

#### **Limitations, Deficiencies, Problems**

- Existing tools do not provide the needed data management and documentation capabilities.

## **A2.2 FUNCTIONAL ANALYSIS**

Functional decomposition analysis is a method of analyzing performance requirements and dividing them into discrete tasks or activities. It identifies and decomposes the primary system functions to ever increasing levels of detail, with allocation of functions to system elements and definition and allocation of performance requirements at each analysis level.

Functional decomposition analysis is performed at all levels of design. It is used wherever the design is broken down to increasing levels of detail. Systems Engineering uses it to decompose the high-level design concepts down to the line replaceable unit (LRU) level. Detailed Design uses it to decompose the LRU down to individual components.

### **A2.2.1 Functional Requirements Analysis and Allocation**

Functional analysis is performed to identify the characteristic actions of all the system elements (hardware, software, facilities, personnel, procedural data, or combinations thereof) and the performance requirement for each function to the level of detail required to initiate production design and specify required performance for each configuration item (CI) and position.

Functional requirements analysis and allocation is part of functional analysis. It consists of functional flow analysis, functional allocation, performance requirements analysis and allocation, and functional analysis of changes.

Used by Systems Engineering when the design is being decomposed, this process occurs from the concept development phase through detailed design.

### **A2.2.1.1 Functional Flow Analysis**

#### **Description**

The functional analysis technique and format assist in identifying subfunctions and provide visibility of sequential and parallel relationships between functions. Each function has a unique identifier that can be used to trace to both higher (parent) and lower (child) level functions.

#### **Purpose**

- To identify system functions and their sequential relationships from the top down in a methodical, disciplined analysis.
- To provide traceability from all levels up to the system and mission objectives and requirements.

#### **Tools**

- Specification and requirements capture tools: RDD100 (Ascent Logic).

#### **Inputs**

- System description.

#### **Outputs**

- Functional flow document.

#### **Where It Fits in the Design Process**

**Phase Application:** Although formal functional flows are not normally developed until the CD/V phase, informal flows are used in every phase and at every level. Formal functional flows at the system and segment level should be complete by the end of the CD/V phase, and at the prime or critical item and operator level early in the FSD phase. These flows are established by Systems Engineering based upon inputs from all design organizations.

**Prerequisites:** Mission and system objectives, a baseline mission profile, and a baseline operational concept should be established and documented before formal functional flow analysis starts. The functional flow is prerequisite to functional allocation and functional performance analysis and should precede preparation of specifications at each level.

#### **Limitations, Deficiencies, Problems**

- Available tools not sufficiently robust for large scale programs.
- Available tools have limited representation, analysis, documentation, and data management capabilities.

### **A2.2.1.2 Functional Allocation**

#### **Description**

Each function generated by the functional flow analysis is allocated to hardware or software CIs, personnel and procedures, external systems, or logistic support subsystems via the system hierarchy (segments, elements, subsystems, etc.). An accounting of the allocation and rationale is maintained.

#### **Purpose**

- To allocate required functions to functional areas, segments, subsystems, hardware and software configuration items, personnel, procedural controls, external interfaces, or the maintenance and support logistics subsystem.
- To maintain an accounting of the allocations made.

#### **Tools**

- Specification and requirements capture tools: RDD100 (Ascent Logic).

#### **Inputs**

- Functional flow data.
- System requirements.

#### **Outputs**

- Functional allocations.

#### **Where It Fits in the Design Process**

**Phase Application:** Functional allocations to the CI level are established by Systems Engineering based on inputs provided by all design organizations. The analysis should be initiated after, but performed in conjunction with, the functional flow analysis at each level in the design (system, subsystem, LRU, etc.). A comprehensive analysis should precede specification preparation. The allocations established during each design phase is determined by the level of design definition required in each phase.

**Prerequisites:** Functions to be allocated as well as a preliminary definition of the system to the level to which functions are to be allocated must be defined.

#### **Limitations, Deficiencies, Problems**

- Available tools not sufficiently robust for large scale programs.
- Available tools have limited representation, analysis, documentation, and data management capabilities.

### **A2.2.1.3 Performance Requirements Analysis and Allocation**

#### **Description**

Verifiable performance, resource, and task requirements must be determined and documented for each function identified by the functional flow analysis. They are allocated to system hierarchical elements and configuration items.

#### **Purpose**

- To analyze, derive, quantify, and document the performance requirements for each function and task.
- To allocate these requirements to system CIs, facilities, operating personnel, or support system elements.
- To identify and define tasks and required resources and allocate them to the system elements.

#### **Tools**

- Specification and requirements capture tools: RDD100 (Ascent Logic).

#### **Inputs**

- Requirements for inspection, demonstration, analysis, or test.
- System requirements.
- Success criteria for each performance requirement.

#### **Outputs**

- Documented requirement allocations.

#### **Where It Fits in the Design Process**

**Phase Application:** Performance allocations to the CI level are established by Systems Engineering based on inputs provided by all design organizations. Draft requirements should be prepared and during the CE/D phase and refined during subsequent design phases. A formal performance requirements and allocation analysis should begin during the CD/V phase and must be completed very early in the FSD phase. A detailed analysis may be required during the early CD/V phase to support the design of critical test or demonstration components. Special attention must be given to scheduling requirements allocation for long-lead items.

**Prerequisites:** The prerequisites to performance requirements analysis and allocation are functional flow analysis and functional allocation. Several supporting analyses, including design and trade studies, are also required. Together with the requirements and constraints that are not allocated and the non-tradeable requirements, the allocated performance requirements are the basis for preparing the specifications. A partially completed performance requirements analysis is a major input to the design synthesis process. Also, performance requirements analysis and allocation is a major interface with software and logistics

#### **Limitations, Deficiencies, Problems**

- Available tools not sufficiently robust for large scale applications.
- Available tools have limited representation, analysis, documentation, and data management capabilities.



#### **A2.2.1.4 Functional Analysis of Changes**

##### **Description**

Class I and Class II changes must be integrated into the baseline system functional analysis to ensure identification of all affected parts of the system, retain decision rationale, and maintain configuration accounting.

##### **Purpose**

- To maintain the functional baseline.
- To provide discipline on changes equal to the initial design.
- To aid in integration of changes.

##### **Tools**

- None commercially available.

##### **Inputs**

- Changes required to design.
- System description.
- System requirements.

##### **Outputs**

- Documentation of changes needed in design.
- Documentation of items affected by changes.

##### **Where It Fits in the Design Process**

**Phase Application:** Functional analysis of changes is performed by the group that currently has control of the design. Systems Engineering performs this task until the LRU design phase and then Detailed Design takes over.

**Prerequisites:** Prerequisites are data from the baseline functional, the functional allocation, and the performance requirements analysis and allocation analyses.

## **A2.2.2 Supporting Analyses**

The functional analysis process includes many supporting analyses. Several of the most important are performed by the engineering specialties, logistics, and the technical staff. The logistics support analysis in particular must be well integrated with the system functional analysis. Functional analysis methods are also used in performing the supporting analyses.

The supporting analyses include but are not limited to mission analysis, timeline analysis, operational sequence diagrams, failure mode analysis, repair-level analysis, design constraints analysis, and deployment planning analysis.

### **A2.2.2.1 Mission Requirements Analysis**

#### **Description**

When mission objectives are lacking or incomplete, the mission must be analyzed to develop primary and secondary mission scenarios or profiles with supporting detail for each phase of the mission.

#### **Purpose**

- To develop a thorough understanding of the mission of the system under development.
- To break the mission into its component elements.
- To document the baseline primary and secondary missions of the system, including the threats to be encountered while performing them.

#### **Tools**

- None commercially available.

#### **Inputs**

- Operational environment and requirements.
- Mission requirements.
- Operational concept.

#### **Outputs**

- Documentation of primary and secondary mission profiles.
- Documentation of profiles of mission phases.

#### **Where It Fits in the Design Process**

**Phase Application:** Mission analyses should be performed to varying degrees of completeness until the CI specifications are finalized. The baseline scenarios should be established at the beginning of the CE/D phase as various concepts are explored. The basic primary and secondary missions should be firm by the beginning of the CD/V phase, as the intent should be to verify the validity of chosen design concepts.

#### **A2.2.2.2 Operating Concept Studies**

##### **Description**

Studies should develop an in-depth understanding of how the system will be operated by the user in performing each phase of a mission for each operating mode. This understanding is input to the functional flow and requirements analyses.

##### **Purpose**

- To postulate alternative concepts for operating the system to satisfy the identified mission needs and evaluate their effectiveness, relative cost, and technical risk.
- To identify the primary and secondary operating modes.
- To develop an initial technical definition of required external interfaces.

##### **Tools**

- None commercially available.

##### **Inputs**

- Customer measures of effectiveness.
- Mission requirements.
- System concepts.

##### **Outputs**

- Documented operating concepts.
- Documented operating modes.
- Documented external interfaces.

##### **Where it Fits in the Design Process**

**Phase Application:** Operating concept studies should be emphasized heavily during the CE/D phase, and baseline operating concepts should be established by the beginning of the CD/V phase. The results of the CD/V phase may drastically alter the operating concepts. The operating concepts should be fully established by very early in the FSD phase.

### **A2.2.2.3 Timeline Analysis**

#### **Description**

Timeline analyses or equivalent statistical models identify time-critical functions and tasks and allocate performance time requirements to subfunctions and tasks.

#### **Purpose**

- To determine whether time is a critical factor for individual functions or between functions.
- To identify the time-critical tasks.
- To quantify action and reaction times and operator workloads.

#### **Tools**

- None commercially available.

#### **Inputs**

- Process descriptions.
- Schedule requirements.

#### **Outputs**

- Time-critical functions and tasks documented.

#### **Where It Fits in the Design Process**

**Phase Application:** The level of detail in the timeline analyses should progress through the acquisition phases in parallel with mission analysis, operational concept studies, and functional identification and performance requirements analyses. The technique is used extensively during the FSD phase.

#### **A2.2.2.4 Operational Sequence Diagrams**

##### **Description**

Operational sequence diagrams provide a means of visualizing and analyzing critical sequences of events.

##### **Purpose**

- To visualize, analyze, and portray the sequence of events and actions required to perform critical system operations.

##### **Tools**

- None commercially available.

##### **Inputs**

- Functional flow analysis.
- Operational requirements.

##### **Outputs**

- Critical sequences of events documented.

##### **Where It Fits in the Design Process**

**Phase Application:** For systems having sequence-critical operations, operational sequence diagrams are used as an analysis tool during any phase. They are also used as an input to system operating procedures (technical orders, software development, operator position descriptions, etc.) and should be completed by the beginning of system testing during the CD/V or FSD phases.

### **A2.2.2.5 Failure Modes Analysis**

#### **Description**

Failure modes analyses (FMA) must be performed in support of functional analysis and allocation to determine the criticality of the failure of each system function or element, the system's response to failures, and requirements for detecting and isolating failures. Results of more detailed specialty engineering analysis, such as failure rates or maintenance and repair resource requirements, must be integrated into performance requirements analysis and allocation.

#### **Purpose**

- To determine the modes in which system functions or elements can fail, the criticality of each failure to the mission, the means of detecting failures, and the response to each failure.
- To determine if the fault detection and fault isolation system is adequate.
- To provide data to allow development of system maintenance instructions.

#### **Tools**

- Fault tree, Markov, and Monte Carlo modeling tools.
- Fault simulators: QuickFault, High Low III, LASAR, SABER.

#### **Inputs**

- System description and block diagrams.
- Operational modes and stimuli.
- Failure rates.
- Fault dictionary.

#### **Outputs**

- Documented recommendations for changes in the design of fault containment regions and fault monitors.
- Fault matrix.

#### **Where It Fits in the Design Process**

**Phase Application:** Preliminary, high-level failure mode analyses are started during concept development in the CE/D phase. The formal failure mode analysis is performed in parallel with the functional analysis, beginning in the CD/V phase and finishing in the FSD phase. Failure mode analyses must be performed in support of functional analysis and allocation. This analysis is generally performed by a dedicated FMA group.

#### **Limitations, Deficiencies, Problems**

- FMA is primarily a manual process and very time consuming.
- A comprehensive FMA requires detailed information (circuit schematics) that is generally not available until late in the design cycle. As a result, critical deficiencies require costly redesign.

### **A2.2.2.6 Repair-Level Analysis**

#### **Description**

A repair-level analysis (RLA) is used in conjunction with life cycle cost analysis to determine the optimum location for performing repairs or maintenance. Preliminary repair analyses are an integral part of system concept studies for systems posing questions about unusual repair locations (such as space-based systems). A complete RLA is a part of the logistics support analysis.

#### **Purpose**

- To determine the optimum location for performing maintenance repairs.

#### **Tools**

- Network Repair Level Analysis Model (AFALC/LSS Wright-Patterson AFB).

#### **Inputs**

- Failure rates.
- Repair times.
- Repair cost estimates.

#### **Outputs**

- Repair level recommendations.
- Detailed repair level costs
- Maintenance requirements.

#### **Where It Fits in the Design Process**

**Phase Application:** Initial, high level analyses are begun during concept formulation in the CE/D phase. Detailed analyses for individual components are completed by the end of the FSD phase. The complete RLA is a part of the logistics support analysis.

#### **Limitations, Deficiencies, Problems**

- Available tools not integrated with existing electronic design systems.
- Available tools do not effectively address all data management and documentation needs

#### **A2.2.2.7 Design Constraints Analysis**

##### **Description**

The design constraints analysis is performed at the CI level to develop, collect, and document specification requirements that are not strictly performance requirements; these include weight, envelope, reliability, design, and construction. A design constraints scoping matrix, plotting constraints against each CI (including logistics support equipment), is prepared.

##### **Purpose**

- To develop and document in specification-type language the design constraints, quantified where possible, applicable to each CI.

##### **Tools**

- None commercially available.

##### **Inputs**

- Requirement allocation sheets (RAS).
- Specification requirements.
- Performance requirements analysis and allocation data.

##### **Outputs**

- Design constraints.
- Design constraints scoping matrix.

##### **Where It Fits in the Design Process**

**Phase Application:** The design constraints analysis is primarily applicable to the FSD phase between system design review and the final or system-level critical design review. Preliminary, high-level analysis should be considered during the later part of the CE/D phase or, for prototype or test articles, during the CD/V phase.



#### **A2.2.2.8 Deployment Planning Analysis**

##### **Description**

Planning for deployment and activation of a system should use the same methods and practices used for development of the system to identify resource, technical data, and safety requirements. Initial operating capability may require temporary or partial system configurations.

##### **Purpose**

- To identify and allocate the functions and resources required to deploy and activate the system.

##### **Tools**

- Mission analysis, life cycle cost, etc. programs such as those listed in Table A-1.

##### **Inputs**

- Installation and checkout requirements analysis.
- Operational requirements.
- System descriptions.
- Site or environmental descriptions.

##### **Outputs**

- Deployment plans and schedules.

##### **Where It Fits in the Design Process**

**Phase Application:** Preliminary analysis of deployment and activation should begin during the concept exploration phase for systems for which these are critical tasks. During the CD/V and FSD phases, the activation and deployment analysis should lag slightly behind the system definition. The analysis should be complete by very early in the production and deployment phase or by the end of the FSD phase.

##### **Limitations, Deficiencies, Problems**

- Available tools not well integrated.
- Available tools do not provide adequate data management and documentation capabilities.

### **A2.3 DESIGN SYNTHESIS**

At each level of the functional analysis, designs that satisfy the functional and performance requirements are synthesized to the level of detail appropriate for the analysis level. That design then guides the next level of functional analysis and derivation of performance requirements. Verification requirements and facility requirements are also developed for each level.

The purpose of design synthesis is to develop a system design that accomplishes the baseline mission and system objectives and requirements and meets the performance requirements for each allocated function. The level of detail of the postulated system will vary from very broad conceptual designs to detailed assembly and production drawings, depending on the phase of the project. Each aspect of the design is evaluated as it is proposed and may be modified as a result of the evaluations, in a repeating cycle. Developing a design solution for the system is an integral part of systems engineering, but the design work is usually performed in organizations that are not called Systems Engineering. A major responsibility of the Systems Engineering organization during synthesis is to constantly review and check to ensure that the various parts of the system are integrated.

#### **A2.3.1 Concept and Design Integration**

The elements of postulated designs or concepts must be integrated into a workable whole by investigation and definition of interfaces and interactions between the elements.

### **A2.3.1.1 State-of-the-Art Surveys**

#### **Description**

To increase competitiveness and reduce technical risk, knowledge of the state of the art of technologies pertinent to the system under design must be maintained by literature searches, experiments, and supplier surveys.

#### **Purpose**

- To determine the state of the art in technological fields involved in a particular mission or system.
- To provide input to conceptual design studies (sec. A2.3.1.2) and system software architecture studies (sec. A2.3.1.3).
- To provide information for use throughout the design phase.

#### **Tools**

- None commercially available.

#### **Inputs**

- Review of technical journals and papers.
- Contacting and visiting suppliers.
- Literature searches.

#### **Outputs**

- State-of-the-art survey report.

#### **Where It Fits in the Design Process**

**Phase Application:** The primary application is during the CE/D phase for systems involving new concepts or technology that is pushing the state of the art. Product improvement modifications may require initiating new surveys in specialized subject areas.

**Prerequisites:** The mission and system objectives and requirements should be well understood in order to focus the survey (secs. A2.1.1.3, A2.1.1.4, A2.1.2.2, and A2.1.2.3).

#### **Limitations, Deficiencies, Problems**

- Manual and time consuming process. Survey results become obsolete quickly.

### **A2.3.1.2 Conceptual Design Studies**

#### **Description**

Baseline and alternative system design concepts are studied to visualize the resulting system, develop preliminary constraints and performance requirements, provide information for evaluation by trade studies, and identify areas of technical risk requiring further development.

#### **Purpose**

- To explore, through design studies, the concepts postulated for satisfying mission and system requirements.
- To begin to turn concepts into tangible designs.
- To feed the conceptual designs developed back to functional analysis (sec. A2.2) in cycles for refinement and amplification of the tasks involved in functional analysis.
- To continually evaluate the conceptual designs (sec. A2.4) and serves as a major input to identification of trade studies (sec. A2.4.1.2).

#### **Tools**

- Mission analysis, life cycle cost, etc. programs such as those listed in Table A-1.

#### **Inputs**

- Preliminary design.
- State-of-the-art knowledge.

#### **Outputs**

- Conceptual design studies.

#### **Where It Fits in the Design Process**

**Phase Application:** Although design studies of varying scope continue throughout the life of a program, conceptual design studies are performed predominantly during the CE/D phase.

**Prerequisites:** Knowledge of the state of the art (sec. A2.3.1.1), mission and system objectives and requirements (secs. A2.1.1 and A2.1.2), and required high-order functions (sec. A2.2.1.1) is needed.

#### **Limitations, Deficiencies, Problems**

- Available tools not integrated.
- Available tools do not provide adequate data management capabilities.

### **A2.3.1.3 System Software Architectural Studies**

#### **Description**

The system and high-level software architecture is portrayed on a diagram showing the relational arrangement of the physical elements of the system, software processing nodes, internal and external communication links, communication switching nodes, and communication protocols.

#### **Purpose**

- To develop and document the overall system arrangement, especially for communications and data processing.
- To establish the communication protocols to be used.
- To identify interfaces with other systems and/or command communications external to the system under consideration.
- To develop diagrams of system architecture for use in internal communication of the current working baseline and inclusion in the system specification (sec. A2.5.1.1) and technical review data packages (sec. A2.5.2.7).
- To aid in identifying the subjects of trade studies (sec. A2.4.1.2).

#### **Tools**

- Markov and Monte Carlo modeling tools.

#### **Inputs**

- Preliminary functional flow analysis.

#### **Outputs**

- System software architectural studies.

#### **Where It Fits in the Design Process**

**Phase Application:** The system architecture should be defined to clarify concepts –almost as a means of describing or defining each concept. Thus, the diagrams are prepared and repeatedly refined during the CE/D phase. Refinement should continue through the CD/V phase and into the FSD phase, at least until the system and segment specifications are authenticated.

**Prerequisites:** The preliminary functional flow analysis (sec. A2.2.1.1) and operating concept studies (sec. A2.2.2.2) should be available for the definition of system architecture to start. Conceptual design studies should progress in parallel, with constant interchange between them and the system architecture studies.

#### **Limitations, Deficiencies, Problems**

- Available tools have limited representation and analysis capabilities.
- Available tools do not provide adequate data management capabilities.

#### **A2.3.1.4 Models and Mockups**

##### **Description**

Physical, analytical, and computer models are used to help visualize all or part of the system and to analyze system response to events and stimuli.

##### **Purpose**

- To assist in visualizing and communicating the form of designs.
- For analytical, computer, and statistical models, to assist in visualizing and determining system response to various stimuli.
- To be used interactively with conceptual design studies (sec. A2.3.1.2) and block diagrams (sec. A2.3.1.5).
- To feed back information to functional allocation (secs. A2.2.1.2 and A2.2.1.3).

##### **Tools**

- MCAD solid and wire-frame modeling tools.
- ECAD/ECAE schematic capture and documentation tools.

##### **Inputs**

- Design specifications and descriptions.

##### **Outputs**

- Model or mockup

##### **Where It Fits in the Design Process**

**Phase Application:** Modeling is used during all phases, but predominantly during the CE/D and CD/V phases. Mockups are primarily used during the later part of the CD/V phase and the early part of the FSD phase.

**Prerequisites:** Proposed designs from the design organization and conceptual design studies (sec. A2.3.1.2) are needed.

##### **Limitations, Deficiencies, Problems**

- Available tools have limited representation and analysis capabilities.
- Available tools not well integrated.
- Available tools do not provide adequate data management capabilities.

### **A2.3.1.5 Block Diagrams**

#### **Description**

Schematic block diagrams are prepared for the system and for major subsystems to portray component functions, physical interconnectivity, and the flow of information or fluids between components. Schematic block diagrams are more detailed than system architecture diagrams.

#### **Purpose**

- To schematically portray the relationship and interconnectivity between functions and/or physical components of a system or subsystem.
- To document the system baseline functional block diagrams (sec. A2.5.2.2) and serve as input to the system schematics (sec. A2.5.2.6).
- Frequently, to be included in the technical review data packages (sec. A2.5.2.7).
- To define the need for and preliminary input to the interface control documents (sec. A2.5.2.8).
- To serve as input to system models (sec. A2.3.1.4) and verification requirements (sec. A2.3.2).

#### **Tools**

- ECAE/ECAD schematic capture and documentation tools.

#### **Inputs**

- Functional flow analysis
- Requirements allocation sheets (RAS).

#### **Outputs**

- Schematic block diagrams and documentation.

#### **Where It Fits in the Design Process**

**Phase Application:** Block diagrams may be used in any phase and at any level, but formal documentation begins primarily in the CE/D and later phases. The diagrams should be complete and under at least internal configuration control by early in the FSD phase. Similarly, the block diagrams for prototype articles constructed for evaluation during the CD/V phase should be placed under configuration control.

**Prerequisites:** System architecture diagram (sec. A2.3.1.3) and functional flow analysis (sec. A2.2.1.1) should be initiated at each analysis level before the block diagrams. There is a constant interaction with the functional flow analysis as each level is analyzed.

#### **Limitations, Deficiencies, Problems**

- Available tools do not provide adequate data management capabilities.

### **A2.3.1.6 Supplier Surveys**

#### **Description**

Supplier surveys are conducted to determine the design skills and products available from industry to support state-of-the-art surveys, conceptual designs, design/buy and make/buy decisions, and trade studies.

#### **Purpose**

- To determine the design skills and products available from industry to support the concepts and system designs under consideration.
- During the FSD and production and deployment phases, to determine the quality and production capacity (producibility) of selected suppliers.
- To support trade studies (sec. A2.4.1.2), functional analysis (sec. A2.2), design studies (sec. A2.3.1.2), architectural studies (sec. A2.3.1.3), block diagrams (sec. A2.3.1.5), and producibility evaluations (sec. A2.4.1.3).

#### **Tools**

- None commercially available.

#### **Inputs**

- Same as state-of-the-art surveys.

#### **Outputs**

- Supplier survey results and reports.

#### **Where It Fits in the Design Process**

**Phase Application:** Supplier surveys may be part of state-of-the-art surveys during the CE/D phase. They are used separately to support functional analysis, design studies, and architectural studies during the CE/D, CD/V, and FSD phases. They support block diagrams and producibility evaluations during the early FSD phase and trade studies during all phases.

**Prerequisites:** Mission and system objectives and requirements (sec. A2.1), initial functional flow analysis (sec. A2.2.1.1), and initial state-of-the-art surveys (sec. A2.3.1.1) must be started.

#### **Limitations, Deficiencies, Problems**

- Manual and time consuming process. Survey results become obsolete quickly.



### **A2.3.1.7 Specification Tree**

#### **Description**

The specification tree portrays the hierarchical relationship for all the specifications applicable to a system. Specifications must represent each deliverable item or increment of the system, and the tree must parallel the work breakdown structure (WBS). The tree will determine the list of CIs.

#### **Purpose**

- To identify and document the hierarchical relationship of all specifications for a system down to the lowest CI level.
- To provide administrative control of preparation of the specification baseline (sec. A2.5.1) and information in the technical review data packages (sec. A2.5.2.7).
- To identify interfaces between suppliers' products that require interface control documents (sec. A2.5.2.8).

#### **Tools**

- Specification and requirements capture tools: RDD100 (Ascent Logic).

#### **Inputs**

- Work breakdown structure.

#### **Outputs**

- Specification tree.

#### **Where It Fits in the Design Process**

**Phase Application:** Draft trees should be prepared during the CE/D and early CD/V phases for feasible system concepts. Late in the CE/D phase, a tree should be prepared as part of the proposal for the CD/V phase. Similarly, a tree should be prepared late in the CD/V phase as part of the proposal for the FSD phase. The tree should be complete, agreed to with the customer, and under internal configuration control early in the FSD phase, prior to authentication of the FSD system specification. Engineering change proposals throughout the life of the system may cause changes to the tree.

**Prerequisites:** Functional allocation (sec. A2.2.1.2), system architecture (sec. A2.3.1.3), and block diagrams (sec. A2.3.1.5) are required.

#### **Limitations, Deficiencies, Problems**

- Available tools not sufficiently robust for large scale applications.
- Available tools have limited representation, analysis, documentation, and data management capabilities.

### **A2.3.2 Verification Requirements**

Requirements are developed for verifying that each performance and design requirement has been satisfied. The statement of verification requirements must include the criteria by which completion will be judged successful. Traceability must be maintained between the requirement being verified, the verification requirement, and the evidence of compliance. Verification of individual requirements is completed at the lowest level possible in the system.

Development of formal verification requirements during the synthesis of a concept or system design is an integral part of the synthesis process. By developing the test concepts and methods at the same time as the design, designs and requirements that are not testable or require disproportionate resources to test can be modified or rejected. Similarly, requirements for built-in test or features that aid testing can be determined early, which will not only help the verification program but also improve maintainability.

The formal verification process is generally called the "test program," but demonstrations, analyses, and special engineering inspections are also used to verify compliance with the specification requirements. The formal verification program does not include engineering experimental and developmental testing.

In most cases, several copies of each CI are produced to the same design. In those cases, the design is qualified during the verification program, and quality assurance in production verifies that each copy is the same as the qualified design. At the segment and system level, however, it is common to produce only one item, or very few items, so it is not cost effective to qualify the design in the same way as for a production run. In these cases, as much verification as possible is performed at lower levels, but final verification is usually performed on the whole system to be delivered, or even at delivery, to verify that the system as a whole complies with the requirements of the specification. Traceability must be maintained from the requirements to the reports and analyses that verify compliance so that complete compliance with the specification is documented for contract closeout.

### **A2.3.2.1 Test Concepts**

#### **Description**

The overall plan and concept for the test program must be documented, usually in the system test plan. The test concept must be consistent with the test and evaluation management plan (TEMP) if one is furnished by the customer. A building-block concept, proceeding from the lowest level components up to the system level, is considered standard.

#### **Purpose**

- To provide an overall concept for structuring the verification program that establishes and confirms the performance of the system and provide a basis for acceptance of production articles and the assembled system.
- To be used in preparation of the system specification (sec. A2.5.1.1), source control documents (SCD) (sec. A2.5.1.4), and development test plans (sec. A2.4.2).

#### **Tools**

- None commercially available.

#### **Inputs**

- Test instruction sheets (TIS).
- Test requirements.

#### **Outputs**

- System test plan.

#### **Where It Fits in the Design Process**

**Phase Application:** Preliminary development of the test concept occurs during the CE/D phase. The concept is refined and upgraded during the CD/V phase. It must be firm by the beginning of the FSD phase.

**Prerequisites:** The system architecture and general composition (sec. A2.3.1) must be known. The organization and the WBS must have been selected. At least preliminary performance requirements (sec. A2.2.1.3) must be established.

#### **Associated Military Documents**

- DODD 5000.3, Test and Evaluation.

### **A2.3.2.2 System Verification Requirements**

#### **Description**

A verification requirement is documented for each performance and design requirement of each specification. It contains the criteria for successful verification. A single test, demonstration, inspection, or analysis frequently verifies several individual requirements. Verification requirements should be stated so they can be completed at the lowest possible level of system component or subassembly. Traceability between performance and verification requirements must be maintained.

#### **Purpose**

- To establish specific requirements for verifying the design and performance requirements of the system, segment, and configuration item specifications.
- To be used in completion of the specifications (sec. A2.5.1).
- To initiate planning for formal verification testing (secs. A2.4.2.3 and A2.4.2.4).

#### **Tools**

- None commercially available.

#### **Inputs**

- Success criteria for verification requirement.

#### **Outputs**

- Verification cross-reference matrix.

#### **Where It Fits in the Design Process**

**Phase Application:** Verification requirements should be considered during the CE/D phase but are not formally documented until the specifications are written. Verification requirements for demonstration articles will be required in the CD/V phase and must be completed for the operational system before the test program of the FSD phase begins.

**Prerequisites:** The test concept (sec. A2.3.2.1) must be developed, as must the specification design and performance requirements (sec. A2.2.1.3).

#### **Associated Military Documents**

- MIL-STD-490A (Hardware).
- MIL-STD-483A (Software).

### **A2.3.2.3 Checkout Requirements**

#### **Description**

Requirements for Quality Assurance verification that system increments, installations, and subassemblies are operating correctly (checkout) before system development continues must be documented. Increments to be checked out are chosen to aid fault isolation and to ensure that the next assembly or installation operation can be performed without damage to property or injury to personnel.

#### **Purpose**

- To verify that installations are correct and that the installed elements of the system are operating correctly.
- To identify any special equipment, software, and procedures necessary to install, assemble, or connect and check out the system to verify that it is ready for operation.
- Potentially, to impact or influence the design of system elements (sec. A2.4.2.5).

#### **Tools**

- None commercially available.

#### **Inputs**

- Preliminary or final technical orders (TO), if possible.

#### **Outputs**

- Checkout requirements document.

#### **Where It Fits in the Design Process**

**Phase Application:** Checkout concepts and planning should be considered during all phases as the design progresses. Specific checkout requirements are needed for each phase during which deliveries are to be made; for example, test articles during the CD/V phase. Checkout requirements may be prepared late in the FSD phase or early in the production phase; they must be complete prior to production.

**Prerequisites:** Inputs from concept design studies (sec. A2.3.1.2), deployment and activation functional analysis (sec. A2.2.2.8), and hardware and software design during FSD are necessary.

#### **A2.3.2.4 Acceptance Test Requirements**

##### **Description**

Requirements for inspection, demonstration, and testing to verify that production CIs and system delivery increments are acceptable for delivery must be documented. Requirements may be for acceptance by Boeing for future delivery, for acceptance by Boeing's customer, or both.

##### **Purpose**

- To define the inspections, demonstrations, and tests required for acceptance of each delivery CI and system increment by Boeing from suppliers or by the customer from Boeing; i.e., to establish the criteria for successful delivery.
- To provide the technical basis for contractual acceptance of each delivered article, system increment, and system.
- To provide a significant part of the product baseline (sec. A2.5.1).

##### **Tools**

- None commercially available.

##### **Inputs**

- Test verification requirements.
- Completion or design and performance requirements.

##### **Outputs**

- Acceptance test procedures.
- Acceptance test requirements.

##### **Where It Fits in the Design Process**

**Phase Application:** All phases after the CE/D phase that require delivery of articles, increments, or the entire system.

**Prerequisites:** Prerequisites are completion of the design and performance requirements portion of the specifications (sec. A2.5.1), the test concept (sec. A2.3.2.1), and the verification requirements (secs. A2.3.2.2 and A2.3.2.3).

### **A2.3.3 Facility Requirements**

Requirements must be developed and documented for facilities that are an integral part of the system or that house and support the prime mission equipment (PME), the interfaces between the PME and facilities, the design and construction of the facilities, and acceptance of facilities.

This general category of tasks develops the requirements for facility resources to house and support the system under development and defines the interfaces between the facilities and the prime mission equipment. In some cases, the facilities are an integral part of the system being developed, but in others, the facilities simply house and support the prime mission system and its supporting elements.

### **A2.3.3.1 Facility Identification**

#### **Description**

Facilities required as part of the system, to house the system elements, or to support operation and maintenance of the system must be identified and documented.

#### **Purpose**

- To identify and define the facility resources required to house and support the prime mission system.
- To develop the more detailed requirements in the next iteration of the functional performance analysis (sec. A2.2.1.3), interfaces (sec. A2.3.3.2), criteria (sec. A2.3.3.3), and acceptance requirements (sec. A2.3.3.4).
- To be used in communication with outside agencies and contractors.

#### **Tools**

- None commercially available.

#### **Inputs**

- Requirement allocation sheets (RAS).
- Definition of facility resources.

#### **Outputs**

- Documented facility identification criteria and requirements.

#### **Where It Fits in the Design Process**

**Phase Application:** For systems that include the facilities as an integral part of the concept, such as silo-based ballistic missiles, high-level facilities requirements are generated, traded, and evolved very early during the CE/D phase. All specially constructed facilities are long lead, so the requirements should be identified as early as possible in the development phases; frequently, they must be identified and defined in increments to allow design and construction to proceed on schedule. Thus, the major parameters of facilities may have to be identified and put under configuration control during the CD/V phase, prior to starting the FSD phase. During FSD, the facilities requirements should be established very early. Separating the more detailed requirements into separate documentation (secs. A2.3.3.2 and A2.3.3.3) helps the scheduling problem.

**Prerequisites:** Prerequisites are functional analysis (sec. A2.2), system architecture (sec. A2.3.1.3), operational environment and requirements (sec. A2.1.1.4), operational concepts (sec. A2.1.1.6) and system objectives and requirements (sec. A2.1.2).



### **A2.3.3.2 PME/Facility Interface Requirements**

#### **Description**

Requirements for interfaces between prime mission equipment and the facility it is used in must be documented. Transient or temporary and physical interface requirements should be included, as well as permanent mechanical and electrical connection interface requirements.

#### **Purpose**

- To identify and define requirements for physical interfaces between the prime mission equipment installed or used in a facility and the facility.
- To be input to facility acceptance (sec. A2.3.3.4), facility criteria (sec. A2.3.3.3), and interface baseline control (sec. A2.5.2.8).
- To be used in communication with agencies and contractors designing the facilities.

#### **Tools**

- None commercially available.

#### **Inputs**

- Preliminary designs of items to be installed.
- Block diagrams.
- Facility identification.

#### **Outputs**

- Facility interface requirements document.

#### **Where It Fits in the Design Process**

**Phase Application:** Specific information about facility interfaces is not normally developed until the PME is fairly well defined. For prime or critical CIs, evaluation of facility interfaces may be required during the CE/D phase as an input to trade studies. For test or demonstration installations, complete definition may be required during the CD/V phase; however, detailed interface requirements are not usually developed until the FSD phase. Schedule demands for long-lead facilities may require early partial definition of interfaces, with incremental releases until they are complete. If the customer considers construction of facilities to be part of the production phase, the start of the production phase will overlap the FSD phase, so the demand timing of facility interface definition will change little.

**Prerequisites:** Prerequisites are block diagrams (sec. A2.3.1.5), facility identification (sec. A2.3.3.1), and layouts or preliminary designs of the items to be installed in the facility.

### **A2.3.3.3 Facility Criteria**

#### **Description**

Documentation of facility criteria must include, directly or by reference, all requirements imposed by the system on facilities for the system. Requirements are written in specification-like language. The agency procuring the facilities normally prepares the specifications incorporating the facilities criteria.

#### **Purpose**

- To provide formal documentation of the specification-type requirements imposed by the mission system on facilities.
- To serve as input for facility acceptance documentation (sec. A2.3.3.4), baseline documentation (sec. A2.5.2.10), and communication with external facilities agencies and contractors.

#### **Tools**

- None commercially available.

#### **Inputs**

- Engineering requirements.
- Manufacturing requirements.

#### **Outputs**

- Facilities requirements documents.
- Facilities criteria document.

#### **Where It Fits in the Design Process**

**Phase Application:** For test prototypes, the criteria for those facilities needed to complete the demonstration and tests are documented during the CD/V phase. Similarly, criteria for long-lead facilities needed during the FSD phase may have to be prepared during the CD/V phase. Normally the facilities criteria are prepared during the design portion of the FSD phase.

**Prerequisites:** Prerequisites are requirements analysis and allocation (sec. A2.2.1), system architecture (sec. A2.3.1.3), facility identification (sec. A2.3.3.1), and PME/facility interface requirements (sec. A2.3.3.2).

#### **Associated Military Documents**

- MIL-STD-490A, Specification Practices.

#### **A2.3.3.4 Facility Acceptance**

##### **Description**

The technical inspections, tests, demonstrations, and analyses performed or audited prior to acceptance of facilities must be documented; routine quality assurance inspections may be omitted. Acceptance requirements must not impose requirements not included in the facilities criteria to which the facility was constructed.

##### **Purpose**

- To plan and document the engineering requirements for inspection and test of facilities prior to acceptance or turnover for installation of mission equipment.
- To transmit engineering requirements to Operations.

##### **Tools**

- None commercially available.

##### **Inputs**

- Facility criteria.
- Engineering requirements for acceptance and test.

##### **Outputs**

- Facility acceptance requirements document.

##### **Where It Fits in the Design Process**

**Phase Application:** Some facilities requiring acceptance may be needed during the CD/V phase for demonstration of prototypes, but normally all system facilities are accepted beginning early in the production and deployment phase. The acceptance requirements should be prepared late in the FSD phase or during the P/D phase before particular facilities need to be accepted; e.g., incrementally.

**Prerequisites:** Facility criteria (sec. A2.3.3.3) and facility criteria baseline control (sec. A2.5.2.10) are needed.

## **A2.4 EVALUATION AND DECISION**

As each design solution is synthesized and postulated, it must be evaluated against the functional and performance requirements of the system, and a decision must be made about whether to move the working baseline to include it. Frequently, the results of the evaluation process feed back to modify functional analysis and generation of requirements or even the system objectives. Trade studies, analyses by specialty engineering disciplines, testing, and program reviews are the major means of evaluation.

### **A2.4.1 Study and Analysis**

Studies and technical analyses supported by engineering tests are the primary tools used to evaluate designs until prototype equipment becomes available. Trade studies, sensitivity analyses, and evaluation analyses by specialty engineering disciplines are the major means of evaluating designs. Technical performance parameters are established to track progress toward performance objectives. Support system analyses evaluate the supportability of proposed designs.

#### **A2.4.1.1 Technical Performance Measurement**

##### **Description**

Requirements for key and critical performance parameters are established as technical performance measurements (TPM). As design progresses and analysis and test data become available, progress toward achieving each requirement is tracked and presented graphically. TPMs are used as a measure of technical program development status by management and the customer. Parameters that are go/no-go or that can be met without development are poor choices for TPMs.

##### **Purpose**

- To periodically forecast the values of selected performance measures to give management early visibility of problems and support assessment of proposed program changes.
- To evaluate the technical status of the program and take timely action if it appears that the program will not meet its technical goals.

##### **Tools**

- None commercially available.

##### **Inputs**

- Analyses, including results of trade and sensitivity studies, to identify key performance areas to be tracked (10 to 12 different parameters).

##### **Outputs**

- TPM report, updated periodically.

##### **Where It Fits in the Design Process**

**Phase Application:** TPMs are normally used late in the CD/V phase, then in the FSD and production phases.

**Prerequisites:** Major prerequisites or inputs to this task are measures of effectiveness, outputs of trade and sensitivity studies; specialty engineering analysis; and concept, design, and operational assessment and test.

##### **Associated Military Documents**

- MIL-STD-499A, Engineering Management.
- "Systems Engineering Management Guide," Ft. Belvoir, VA., Defense Systems Management College, Chapter 14, p. 14-1.

#### **A2.4.1.2 Trade Studies and Sensitivity Analyses**

##### **Description**

Trade studies are the decision-making tool used to evaluate and resolve choices between postulated solutions at branches (decision points) in the functional analysis and design synthesis processes. They trade interdependent program or design parameters to determine the best balance between or among the parameters. Sensitivity studies determine the sensitivity of selected parameters to changes in other parameters. Documentation of trades and sensitivity analyses records the rationale for program decisions and provides a baseline for evaluating future changes.

##### **Purpose**

- To determine the best setting for all system parameters that can be controlled by engineering. This includes ensuring that not-to-be-exceeded parameters such as cost are met and that the selected parameters result in a system in which capability is not sensitive to reasonable changes in any of the parameters.
- To make program decisions.
- To serve as inputs in generating the next level of functions and performance requirements in the functional analysis (sec. A2.2.1), making decisions on designs (sec. A2.3.1), and determining intermediate system baselines (sec. A2.5.2).

##### **Tools**

- Mathematical models.
- Mission analysis, life cycle cost, etc. programs such as those listed in Table A-1.

##### **Inputs**

- Figures of merit and measures of effectiveness.
- Alternative systems.
- Functional analyses.

##### **Outputs**

- Trade study results.

##### **Where It Fits in the Design Process**

**Phase Application:** Trade studies are made in all phases of the development cycle. Mission- and concept-level trades are made during the early phases, and detailed trades concerning unexpected changes are made during the late phases.

**Prerequisites:** Inputs to trade studies are functional analysis (sec. A2.2); concept and design integration (sec. A2.3.1); measures of effectiveness (sec. A2.1.1.5); analytical models and simulations (sec. A2.3.1.4); results of specialty analyses such as reliability, safety, and human factors (sec. A2.4.1.3); concept, design, and operations assessment studies (sec. A2.4.1.4); and tests (sec. A2.4.2).

##### **Limitations, Deficiencies, Problems**

- Available tools not well integrated.
- Available tools do not provide adequate data management capabilities.

### **A2.4.1.3 Specialty Engineering Analyses and Evaluations**

#### **Description**

The major specialty engineering disciplines are reliability, maintainability, safety, human factors, electromagnetic compatibility, corrosion control, survivability and vulnerability, producibility, and security engineering. The requirements of these disciplines are included in the performance requirements of the functional analysis and subsequently in the specifications. Postulated design solutions must be evaluated by these disciplines for compliance with requirements.

#### **Purpose**

- To ensure that the design includes all characteristics required by the specialty engineering areas.
- To serve as input to the next iteration of the functional analysis (sec. A2.2) and as feedback to design studies (sec. A2.3.1.2) and specifications (sec. A2.5.1).

#### **Tools**

- Mission analysis, life cycle cost, etc. programs such as those listed in Table A-1.

#### **Inputs**

- Functional analyses.

#### **Outputs**

- Feedback to design studies and specifications.

#### **Where It Fits in the Design Process**

**Phase Application:** Specialty engineering evaluation is performed informally during the CE/D and CE/V phases and formally in developing specification and requirements verification tasks in the FSD and production phases.

**Prerequisites:** Inputs are higher level functions of the functional analysis (sec. A2.2) and concept and design integration data (sec. A2.3.1).

#### **Limitations, Deficiencies, Problems**

- Available tools not well integrated.
- Available tools do not provide adequate data management capabilities.

#### **Associated Military Documents**

- MIL-STD-499A, Engineering Management.

#### **A2.4.1.4 Concept, Design, and Operations Assessment Studies**

##### **Description**

Concept, design, and operations assessment studies are specialized names for trade studies or specialized studies to support trade studies.

##### **Purpose**

- To provide a rational, traceable basis for decisions.
- To provide input to trade studies.

##### **Tools**

- Mission analysis, life cycle cost, etc. programs such as those listed in Table A-1.

##### **Inputs**

- Figures of merit.
- Trade studies.

##### **Outputs**

- Assessments that can be used in future trade studies.

##### **Where It Fits in the Design Process**

**Phase Application:** The assessments are performed throughout the development cycle whenever additional information is needed to determine the feasibility of a concept or design and/or to aid in the selection of the concept or design that best meets the customer's requirements. Conceptual assessments are made in the early phases to evaluate concepts; design and operating assessments are performed as needed to ensure a design meets the customer's requirements and to guide the design process.

**Prerequisites:** Inputs to these assessments are analytic models and simulations, designs, measures of effectiveness, tests, and specialty engineering analyses.

##### **Limitations, Deficiencies, Problems**

- Available tools not well integrated.
- Available tools do not provide adequate data management capabilities.



#### **A2.4.1.5 Support System Analyses**

##### **Description**

Each postulated concept and design must be evaluated for its effect on support subsystems. The cost of maintenance, repair, operator training, and provision of consumables during the life of the system can be nearly as great as the initial procurement cost. Also, the operational readiness of the system depends on the support subsystem.

##### **Purpose**

- To ensure that the effect on the support system is considered during the evaluation and decision process involving concepts, operation, or configurations driven by mission and system requirements.
- To perform trade studies and assessments involving support system concepts, designs, and operations.

##### **Tools**

- Mission analysis, life cycle cost, etc. programs such as those listed in Table A-1.

##### **Inputs**

- Systems engineering definition of a configuration.
- Logistics support analysis (LSA).
- LSA data sheets.

##### **Outputs**

- LSA record (documentation).

##### **Where It Fits in the Design Process**

**Phase Application:** Support system analyses are used throughout the development cycle (secs. A2.4.1.2 and A2.4.1.4). They progress from concept to detailed design configuration as the program progresses.

**Prerequisites:** Prerequisites are system and/or design engineering definition of the operating concepts of configurations to be supported (sec. A2.3.1).

##### **Limitations, Deficiencies, Problems**

- Available tools not well integrated.
- Available tools do not provide adequate data management capabilities. The LSA record database is not readily useable by design engineers.

##### **Associated Military Documents**

- MIL-STD-1388-1.

## **A2.4.2 Test and Evaluation**

A comprehensive test program is required to evaluate the system design, ensure integration of the system, and verify compliance with specification requirements. Engineering development testing is required to reduce risk and evaluate individual concepts and subsystems. Testing is the primary means of ensuring that a high-quality product is produced.

### **A2.4.2.1 Laboratory and Development Tests**

#### **Description**

Engineering laboratory and development testing is required to reduce risk and to develop data in support of design and analytical trade and evaluation studies. This testing is often termed "engineering test and evaluation" when performed on large segments of the system or the whole system.

#### **Purpose**

- To support, supplement, confirm, and/or refine analytical data and predictions.
- To assist in early selection of design concepts and approaches and develop or refine test techniques.
- To verify or validate design approaches and/or probe technology limitations and define areas requiring further development.
- To provide test data to support preliminary design activities (sec. A2.3.1.2), design studies, trade studies (sec. A2.4.1.2), or risk assessment (sec. A2.4.3.2).
- To provide data and insights for selection of feasible concepts for further evaluation and study.

#### **Tools**

- None commercially available.

#### **Inputs**

- Test information sheets.
- System-level requirements.

#### **Outputs**

- Test data to support and substantiate design activities.
- Trade studies or risk assessment.

#### **Where It Fits in the Design Process**

**Phase Application:** Laboratory and development tests are used during the CE/D phase in selecting preferred concepts and approaches. They may also be used by Design in later program phases as part of the normal design and development process.

**Prerequisite:** Initiation of conceptual design studies per section A2.3.1.2 is prerequisite. The tests may also be performed in support of technology assessments (sec. A2.3.1.1).

#### **Associated Military Documents**

- DODD 5000.3, Tests and Evaluations.

#### **A2.4.2.2 Feasibility Tests**

##### **Description**

Feasibility testing is used to prove the concepts or designs on which system feasibility rests. It is a major feature of risk management and the basis for the DOD CD/V phase. Test article configuration should be developed from the functional analysis requirements, and successful testing may eliminate the need for much further functional analysis.

##### **Purpose**

- To identify and validate preferred technical approaches, including identification of technical risks and feasible solutions.
- To provide test data necessary to—
  - Validate concepts and approaches (sec. A2.3.1.2).
  - Select a preferred concept for follow-on development (sec. A2.4.1.2).
  - Define follow-on development requirements and risks (secs. A2.2.1.2 and A2.4.3.2).

##### **Tools**

- None commercially available.

##### **Inputs**

- System-level requirements.

##### **Outputs**

- Test data necessary to validate concepts and approaches.

##### **Where It Fits in the Design Process**

**Phase Application:** The primary use of feasibility tests is during the CD/V phase. Such tests may be selectively or incrementally used during the CE/D phase.

**Prerequisites:** Prerequisites are selection of major candidate concepts through the study and analysis process as discussed in sections A2.3.1.1 through A2.3.1.6 and development of engineering test models (sec. A2.3.1.4).

### **A2.4.2.3 Integration Testing**

#### **Description**

Integration testing is used to find and fix problems as the system is built up into a whole. Internal and external interfaces are verified, and effective operation of the system elements as an integrated system is demonstrated. The effectiveness of training and support systems is also demonstrated. The accuracy and suitability of installation and checkout procedures and equipment and readiness for formal verification testing are determined.

#### **Purpose**

- To verify the integrity of the design selected and its ability to meet performance requirements by verifying the validity of system interfaces and effective interaction between the elements.
- To find and fix problems as the system is built up into an integrated whole.
- To verify that design and development of the system have met all conditions prerequisite to initiation of formal verification activities, including parts fabrication and modification, etc.

#### **Tools**

- None commercially available.

#### **Inputs**

- System-level requirements.
- System configuration.

#### **Outputs**

- Test data that verifies that system design and development have met system-level requirements.

#### **Where It Fits in the Design Process**

**Phase Application:** Integration testing is normally performed during the FSD phase, although some initial increments may be accomplished prior to FSD. Some planning must also be done to support FSD proposals, etc.

**Prerequisites:** Baseline set of system requirements (sec. A2.5.1) and a system configuration (sec. A2.5.2) are prerequisites.

#### **Associated Military Documents**

- DODD 5000.3, Test and Evaluation.

#### **A2.4.2.4 Formal Verification and Qualification Testing**

##### **Description**

Formal testing qualifies CIs for production and verifies that the system complies with its procurement specifications and is ready for acceptance. Rigorous configuration control is required and test articles should be built by production personnel using production tools. Testing should include the support subsystem and tryout of deliverable technical data. If multiple production systems are to be delivered, acceptance testing of each is required.

##### **Purpose**

- To verify the design and the fabrication process and ensure the design integrity of the system over the specified operational and environmental range. From an evaluation and decision standpoint, preproduction qualification ensures the readiness of configuration item designs for production, and verification tests verify that the system is ready for deployment or delivery. The testing provides a baseline for acceptance tests and for introduction of system changes. Production qualification and verification confirms both the design and the production process.
- To ensure and document closeout of contractual requirements. This is extremely critical. Ongoing records of test results, completions, and acceptance must be maintained throughout the entire process, including an agreed-to evaluation of any retests required as a result of approved changes.

##### **Tools**

- None commercially available.

##### **Inputs**

- Product baseline.
- Integration testing.

##### **Outputs**

- Test data that verifies the design and functional integrity of the system.

##### **Where It Fits in the Design Process**

**Phase Application:** Formal testing is applicable to the FSD phase and production and deployment. It has an especially critical role in the transition from the FSD phase to production.

**Prerequisites:** Product baselining per section A2.5 and integration testing per section A2.4.2.3 are required.

##### **Associated Military Documents**

- DODD 5000.3, Test and Evaluation.

#### **A2.4.2.5 Checkout Procedures Tryout**

##### **Description**

Procedures used to install and check out deliverable systems at remote locations must be validated by tryout. Maximum use should be made of deliverable maintenance and operating procedures and of factory functional acceptance procedures. Tryout during installation of test systems is the most effective method of validating the procedures. Safety of equipment, personnel, and surroundings is the primary concern, especially for weapon systems, but the efficiency of fieldwork is also important.

##### **Purpose**

- To verify and debug the procedures used to arrive at the system configuration delivered to the user for operation. Procedures are used to install and check out the system to a point ready for delivery to the user.

##### **Tools**

- None commercially available.

##### **Inputs**

- Installation and checkout requirements analysis.
- Baseline configuration.
- Preliminary or final technical orders (maintenance, etc.).

##### **Outputs**

- Verified and validated checkout procedures and technical orders.

##### **Where It Fits in the Design Process**

**Phase Application:** Validation of checkout procedures occurs late in the FSD phase and early in the production and deployment phase.

**Prerequisite:** Deployment and activation functional analysis per section A2.2.2.8 is required, as is the product (deployment) baseline per sections A2.5.1 and A2.5.2.

### **A2.4.3 Program Evaluation**

Program evaluations of the system design have program and business considerations beyond purely technical evaluation. They include evaluation by the customer and government regulatory agencies.

#### **A2.4.3.1 Life Cycle Cost Analysis**

##### **Description**

Life cycle cost (LCC) analysis forecasts the total ownership cost of a system, including development, acquisition, operation, and retirement. It provides data for trade studies and for program and customer decisions. When completed, an LCC optimization produces a design that meets the requirements for the minimum cost over its lifetime. It is also possible to determine the sensitivity of cost to various parameters. This could help show the possibility of realizing great gains in some areas (performance, repair time, etc.) for very little increase in total cost.

##### **Purpose**

- To ensure that all major decisions are based on an understanding and comparison of cost considerations and effect on the program.
- To optimize the system for minimum cost over the expected life of the system. This can be done at any level of the design, but has the greatest impact at the system level. Changes in the design are more easily incorporated into the design at the system level, but the accuracy may suffer. When done at the detailed design level, the cost estimate is more accurate but changes in the design are much harder to make because of the cost.
- To support study and analysis activities and technical program reviews and formal audits. LCC reports will normally be a contract submittal item, either in support of or as part of trade study reports.

##### **Tools**

- Life cycle cost programs: RCA PRICE.
- CASA

##### **Inputs**

- Baseline system description.

##### **Outputs**

- Documentation of all phases of LCC: development, procurement, operation, and support.
- LCC reports.

##### **Where It Fits in the Design Process**

**Phase Application:** LCC analysis is applicable to all phases. It also applies to all changes after a CI (or system) is formally baselined.

**Prerequisite:** The prerequisite is a baseline system description and/or description of alternatives.

##### **Limitations, Deficiencies, Problems**

- Component cost data becomes obsolete quickly.

#### **A2.4.3.2 Risk Assessment**

##### **Description**

Risks must be assessed and managed throughout the life of a program. Systems engineering methods are specifically designed to reduce program risk. Risk categories are technical performance, management, schedule, cost, logistics, and manufacturing. The Defense Science Board has identified the transition from FSD to production as a major program risk, which can be alleviated by certain practices during system development.

##### **Purpose**

- To identify and assess the effect of risk on the program in the categories of technical performance, management, schedule, cost, logistics, and manufacturing.
- For risks having potentially serious impact, to develop recovery and workaround plans.

##### **Tools**

- Program evaluation review techniques (PERT)-RISNET.
- Life cycle cost model.

##### **Inputs**

- Conceptual design.
- Risk analysis and potential problem analysis.
- Risk assessment.

##### **Outputs**

- Risk management and abatement plan.

##### **Where It Fits in the Design Process**

**Phase Application:** Risk assessment and management are applicable throughout all acquisition phases.

**Prerequisites:** Conceptual design studies (sec. A2.3.1.2) are prerequisite. Risk assessment is interactive with studies and analyses (sec. A2.4.1) and used primarily for program management.

##### **Associated Military Documents**

- MIL-STD-1521B Technical Reviews and Audits for Systems, Equipments, and Computer Software.



### **A2.4.3.3 Technical Program Reviews and Formal Audits**

#### **Description**

Technical program reviews and audits are major milestones in system development, and decisions on proceeding to the next stage of work hinge on a successful outcome. System-level reviews, emphasizing integration of CIs into a system, are held upon completion of the CI-level preliminary and critical design reviews.

#### **Purpose**

- To monitor and assess the technical progress of the program, with emphasis on ensuring that the defined requirements are complete and the evolving design is adequate to meet them.
- To assure the customer and/or management that the program is progressing in a satisfactory manner.
- To serve as a basis for deciding to proceed with the program or make corrections or adjustments deemed necessary or desirable.

#### **Tools**

- None commercially available.

#### **Inputs**

- System baseline (current).
- Preliminary design review.
- Critical design review.

#### **Outputs**

- Assurance that the program is progressing satisfactorily.
- Documented output for decision making.

#### **Where It Fits in the Design Process**

**Phase Application:** Program reviews are held in all phases, but for DOD programs, primarily in the later part of the CD/V and throughout the FSD phases. Initial reviews during early phases concentrate on identification of and concurrence in system requirements. The level of detail progresses through detailed hardware and software design reviews and configuration audits. Figure 1 illustrates the reviews and audits as they match the DOD acquisition system program phases and shows how the reviews match the various baselines.

**Prerequisites:** Prerequisites depend on the nature and type of review: see reference 4, chapter 12 for guidance.

#### **Associated Military Documents**

- MIL-STD-1521B, Technical Reviews and Audits for Systems, Equipment, and Computer Software.

#### **A2.4.3.4 Environmental Impact Statement**

##### **Description**

Many state and federal regulatory agencies require special studies and reports even though the system may be deployed on federally owned land. For non-government customers, there is even more application. Environmental impact statements (EIS) are an example that applies wherever new construction or operation on non-federally controlled land is planned. Over-the-road systems must comply with state highway regulations as well.

##### **Purpose**

- To comply with the National Environmental Policy Act of 1969 (NEPA) as implemented by Executive Orders 11514 and 11991 and the Council on Environmental Quality (CEQ) regulations of November 29, 1978.
- To ensure compliance with both the letter and the intent of the law.
- To help public officials understand environmental consequences and make decisions that result in actions that protect, restore, or enhance the environment.

##### **Tools**

- None commercially available.

##### **Inputs**

- Correlates with identification of facility requirements and facility criteria.

##### **Outputs**

- Environmental impact statement.

##### **Where It Fits in the Design Process**

**Phase Application:** The EIS is applicable in varying degrees to all phases. A separate EIS may be required for prototypes or other special tests or test installations at the system level.

**Prerequisite:** Mission and system requirements must be defined. The EIS may be a factor in measures of effectiveness and/or system constraints.

## **A2.5 BASELINE FOR NEXT CYCLE**

A baseline must be established to begin the next level of analysis or the next phase of a program. The baseline documents the current status of the requirements and configuration, the requirement baseline in the specification set and the configuration baseline in a set of drawings and documents (or book-form drawings).

### **A2.5.1 Specification Baseline**

Specifications are the contractual technical definition of what is being purchased, what it must do, how well it must do it, and what constitutes proof that it does it. From the purchaser's viewpoint, they define a baseline of what is being purchased. The specifications also are the starting point for the product builder and a unifying reference throughout the project. From a systems engineering viewpoint, they are a repository of the performance and configuration requirements developed during each phase and, therefore, a product.

### **A2.5.1.1 System and Segment Specification**

#### **Description**

If not furnished by the customer, a system specification is prepared to define the mission, technical performance requirements, allocation of functions to the next level, design constraints, system external interfaces, and verification requirements.

#### **Purpose**

- To document, for reference in the contract, the technical definition of the system and/or segment mission, performance requirements, and constraints on fabrication and the verification required to prove specification compliance.
- To be used as a contractual and technical baseline for the next phase (sec. A2.1.2.5) and as a major communication and control device within the project.

#### **Tools**

- None commercially available.

#### **Inputs**

- System requirements allocation.
- Technical and performance requirements.
- Mission analysis.

#### **Outputs**

- System and segment specification baseline for the next phase.

#### **Where It Fits in the Design Process**

**Phase Application:** By the end of the CE/D phase, the system and segment specifications should be sufficiently complete to specify all system functions, overall system performance requirements, and functional allocation to prime or critical items. This level of specification is identified as the functional baseline after authentication of the specification. Expansion and revision of system functions to reflect information developed during the CD/V phase plus major quality assurance requirements lead to the system and segment specifications that are part of the allocated baseline (sec. A2.5.1.2) at the end of the CD/V phase. Further completion of the quality assurance requirements and addition of top-level part-number configuration identification and system production acceptance requirements complete the system and segment specifications by the time of the CDR during the FSD phase. This version is part of the product baseline.

**Prerequisites:** Prerequisites are functional allocation (sec. A2.2.1.2) and system requirements analysis and allocation (sec. A2.2.1.3).

### **A2.5.1.2 Configuration Item Specifications**

#### **Description**

A development CI specification, containing performance requirements, constraints, and verification requirements, is prepared for each CI requiring development. A product specification, containing reference to the drawings defining the configuration qualified for production and production acceptance requirements, is also prepared for each CI.

#### **Purpose**

- For CIs that require development, to document, for reference in the contract, the technical definition of each CI's performance requirements and constraints and the verification required to prove compliance with the specification.
- To be used as the contractual and technical baseline for the next phase (sec. A2.1.2.5) and as a major communication and control device within the project for the development of the item.

#### **Tools**

- None commercially available.

#### **Inputs**

- System requirements analysis and allocation.
- Derived requirements allocation.
- Quality assurance requirements.
- MIL-STD-490A, Specification Practices.

#### **Outputs**

- CI specifications.

#### **Where It Fits in the Design Process**

**Phase Application:** CI B specifications may be prepared during the CD/V phase for prototypes or test articles; however, final preparation is usually completed during the early FSD phase. The C specifications are prepared late in the FSD phase, to be completed when the design qualification is completed. The B specifications are part of the allocated baseline, and the C specifications are part of the product baseline.

**Prerequisites:** System and segment specifications (sec. A2.5.1.1), functional allocation (sec. A2.2.1.2), and system requirements analysis and allocation (sec. A2.2.1.3) are required.

#### **Associated Military Documents**

- MIL-STD-490A (Hardware).
- MIL-STD-483A (Software).

### **A2.5.1.3 Commercial Item Documentation**

#### **Description**

Commercial (off-the-shelf) hardware and software and items already in the military inventory must be controlled to ensure that they function correctly in the system, operate in the environment planned, and can be supported for maintenance and repair. However, the cost of such control and testing must be minimized. Purchasing a vendor's specifications, data sheets, test reports, and support is an option.

#### **Purpose**

- To document, for procurement and reference in the contract, the technical definition of the commercial item's performance and the verification required to prove compliance with the specification
- To be used as a contractual and technical baseline for the next phase (sec. A2.1.2.5) and as a major communication and control device within the project.

#### **Tools**

- None commercially available.

#### **Inputs**

- System and segment specifications.
- System requirements.
- Functional allocation.

#### **Outputs**

- Documentation.

#### **Where It Fits in the Design Process**

**Phase Application:** Documentation for items that will not be developed as part of the project (e.g., off-the-shelf hardware) should be complete by the end of the FSD phase. It becomes a part of the product baseline.

**Prerequisites:** System and segment specifications (sec. A2.5.1.1), functional allocation (sec. A2.2.1.2), system requirements analysis and allocation (sec. A2.2.1.3), and proper operation in the system.

#### **Limitations, Deficiencies, Problems**

- Manual preparation of documentation, information seldom available in electronic medium.

### **A2.5.2 Configuration Baseline**

The current configuration of the system baseline should be defined and updated frequently during development; complete documentation is required at the completion of the acquisition phase. A full set of production drawings forms establishes the configuration baseline for the CIs composing the system. Supplementary system-level drawings, indexes, diagrams, and documents are required to document trainers, support systems, facilities, modification kits, etc., in the system configuration.

#### **A2.5.2.1 System Description Document**

##### **Description**

A high-level description of the system and its mission, operation, architecture, and configuration, with references to defining and controlling data, is an excellent integration and communication tool. Because the system description document is not a legal instrument like the system specification and is not subject to Class 1 configuration control by the customer, it can be more responsive to the needs of the program and contain short-term information.

##### **Purpose**

- To provide a top-down portrait of the system that continuously reflects the current level of definition in terms of capabilities and configuration.
- To focus the systems engineering efforts on developing and documenting the design of the system.
- To ensure timely coordination and integration of the system engineering activities and their interfaces with the technologies, design (hardware, software, facilities), logistics, and other specialties and disciplines.

##### **Tools**

- None commercially available.

##### **Inputs**

- CI production drawings.
- Supplementary system-level drawings, indexes, diagrams, and documents.

##### **Outputs**

- Configuration identification and definition document.
- Configuration control document.
- Configuration status accounting.
- Configuration audits.

##### **Where It Fits in the Design Process**

**Phase Application:** The system description document should define the system design status at the beginning and end of each phase. It should be established early in the CE/D phase. It should also support the various design reviews, with special emphasis on formal reviews associated with the functional, allocated, and product baselines.

**Prerequisites:** Initiation of functional analysis activities (sec. A2.2.1.1) and concept and design integration studies (sec. A2.3.1.2).

### **A2.5.2.2 Functional Block Diagrams**

#### **Description**

Functional block diagrams are schematic, symbolic, graphic portrayals of the system or subsystems that provide a comprehensive grasp of how the system is laid out and operates. Blocks or symbols may be used to represent components. The diagrams can be prepared at many levels of detail for differing purposes and should be included in the system description document.

#### **Purpose**

- To define and document baseline system configurations.
- To support baselining of the system design (sec. A2.5.2.1).
- In early phases, to establish and identify alternative configurations being evaluated or studied.
- To establish or divide development responsibilities between organizations and identify functional interfaces.
- As the level of detail increases, to guide, coordinate, and integrate the development of the detailed design, including system schematics that translate the functional and logical modular diagrams to the actual system design.

#### **Tools**

- ECAD/ECAE schematic capture and documentation tools.

#### **Inputs**

- System configuration.
- Alternate concepts.
- Functional interfaces.

#### **Outputs**

- Functional block diagrams document.

#### **Where It Fits in the Design Process**

**Phase Application:** Functional block diagrams are used in all phases. They are informally baselined in early phases to coordinate design development and selection studies. They are a key item in configuration control at the system design level in later phases.

**Prerequisite:** Development of schematic block diagrams during synthesis (sec. A2.3.3.1.5) is required.

#### **Limitations, Deficiencies, Problems**

- Distribution and management of diagrams is not well supported across the available systems.



### **A2.5.2.3 System Interface Definition**

#### **Description**

The external interfaces of the system are defined as part of the baseline to reflect any changes to the system requirements (sec. A2.1.2.4) that have occurred during the phase and to provide a definition for the system requirements (sec. A2.1.2.4) of the next cycle.

#### **Purpose**

- To identify, coordinate, and control system interfaces during the early phases of study and evaluation leading to selection and development of the preferred system design.
- To provide the basis for development of formal interface control data (sec. A2.5.2.8).
- To preserve system integrity as the design evolves through identification and control of interfaces, both internal and external, with respect to the contractor's system design responsibilities.
- To serve as a basis for follow-on preparation of interface control documents (ICD).

#### **Tools**

- None commercially available.

#### **Inputs**

- System requirements.
- Functional block diagrams and analyses.

#### **Outputs**

- Interface control drawings for interface control.
- Interface control documents for the working group.

#### **Where It Fits in the Design Process**

**Phase Application:** The system interface description is used in all phases, pending development of formal ICDs.

**Prerequisites:** Development of schematic block diagrams during synthesis (sec. A2.3.1.5) is required.

#### **Associated Military Documents**

- MIL-STD-483.

#### **A2.5.2.4 Software Architecture**

##### **Description**

Definition of the software architecture in the baseline documentation is necessary to ensure integration of the system design.

##### **Purpose**

- To integrate the development of software into the total system design as it progresses through a series of definable configuration baselines.
- To support baseline definition of the system design.
- To ensure integration of system requirements and software design.

##### **Tools**

- Computer-aided Software Engineering tools.

##### **Inputs**

- System requirements.
- Software design.

##### **Outputs**

- Software architecture definition.

##### **Where It Fits in the Design Process**

**Phase Application:** The software architecture generally follows and correlates with the functional allocation (sec. A2.2.1.2).

**Prerequisite:** Development of block diagrams per section A2.3.1.5 is required.

##### **Associated Military Documents**

- DOD-STD-2167.

#### **A2.5.2.5 Documentation of Alternatives**

##### **Description**

Alternatives considered and evaluated, as well as alternatives not yet resolved, must be documented as a part of the baseline to record the decision process leading to the baseline.

##### **Purpose**

- To document alternative concepts and configurations in support of the evaluation and decision function (sec. A2.4) in order to select a preferred concept or configuration for development.

##### **Tools**

- MCAD solid and wire-frame modeling tools.
- ECAD/ECAE schematic capture and documentation tools.

##### **Inputs**

- Selection of preferred concept or configuration for development.

##### **Outputs**

- Preferred concept

##### **Where It Fits in the Design Process**

**Phase Application:** During early phases, it is used to select system-level concepts and configurations. It may be applied to progressively lower levels of subsystems, configuration items, etc., as the program progresses.

**Prerequisites:** Initial mission and concept studies as defined in section A2.3.1.2 are required.

##### **Limitations, Deficiencies, Problems**

- Available tools have limited representation and analysis capabilities.
- Available tools not well integrated.
- Available tools do not effectively address all data management and documentation needs.

### **A2.5.2.6 System Schematics**

#### **Description**

A set of system schematic diagrams should be prepared and included in the baseline after the functional block diagrams have stabilized.

#### **Purpose**

- To define and document baseline system configurations as they become definite.
- To coordinate the execution of the detailed hardware and/or software design and ensure that the resulting system achieves the desired operational and functional integrity.
- Especially, to ensure coordinated and timely consideration and development of the support system and its elements to match the operational system design as it evolves or is modified.
- To serve as a key element in validation and verification of system design, including comparisons and assessment of effects between test and production configurations.

#### **Tools**

- ECAD/ECAE schematic capture and documentation tools.

#### **Inputs**

- Functional block diagrams.
- System configuration.
- System functional requirements and allocations.
- Interface control drawings.

#### **Outputs**

- System schematics document.

#### **Where It Fits in the Design Process**

**Phase Application:** The system schematics should be baselined after sufficient system definition and prior to or in support of PDR of major system elements. Normally, they will be baselined during the FSD phase. However, on some programs it may be desirable to establish a schematic baseline prior to FSD (e.g., to support development and validation activities or FSD proposal preparation).

**Prerequisite:** Block diagrams (sec. A2.3.1.5) are required.

#### **Limitations, Deficiencies, Problems**

- Available tools do not effectively address all data management and documentation needs.

#### **A2.5.2.7 Technical Review Data Packages**

##### **Description**

Data to be reviewed or presented at formal technical reviews is collected into a package for customer review prior to the meeting. The data packages are retained as the collected baseline at the time of the meeting.

##### **Purpose**

- To support reviews and audits and obtain technical approval and/or direction.
- To provide documented traceability of the review configuration, resulting approvals and/or technical direction, and follow-on implementation and design progression.

##### **Tools**

- None commercially available.

##### **Inputs**

- System configuration baseline.

##### **Outputs**

- Data package to support technical reviews and audits.

##### **Where It Fits in the Design Process**

**Phase Application:** Technical reviews and audits are normally established by the customer and may be applicable to any phase. The primary emphasis is during the CD/V and FSD phases. Those reviews associated with the functional, allocated, and product baselines are emphasized.

**Prerequisites:** Specification and configuration baselining must be established at the appropriate level of detail to support the type of technical review scheduled.

##### **Associated Military Documents**

- MIL-STD-1521B, Technical Reviews and Audits for Systems, Equipments, and Computer Software.

### **A2.5.2.8 Interface Control Drawings**

#### **Description**

Designated interfaces are controlled by interface control drawings or documents. Controlled interfaces should include those with external systems, between different products of contracts with competitively procured products, and with critical internal systems.

#### **Purpose**

- To establish and maintain control of functional and physical interface characteristics that must remain compatible between—
  - Two or more elements that make up the system.
  - The system and any element external to it, including facilities, personnel, etc.
- To serve as part of the system configuration baseline and support technical reviews.

#### **Tools**

- None commercially available.

#### **Inputs**

- System definition or configuration baseline.
- Functional interface characteristics (electrical, hydraulic, pneumatic, mechanical, etc.).
- Physical interface characteristics.
- Technical reviews by interface control working group (ICWG).

#### **Outputs**

- Interface control drawings and documents.

#### **Where It Fits in the Design Process**

**Phase Application:** Normally interface control drawings are applicable during the FSD and follow-on production phases. They become part of the configuration control requirements associated with finalizing design of the CIs and other system elements and maintaining the integrity of the system design through final development and test. They are also critical for transition from the FSD phase to production and deployment.

**Prerequisites:** Functional block diagrams (sec. A2.3.1.5).

#### **Associated Military Documents**

- MIL-STD-483A, Configuration Management Practices for Systems, Equipments, Munitions, and Computer Programs.

### **A2.5.2.9 Design Drawings**

#### **Description**

Released design drawings define and control the configuration of the electrical and mechanical components of the system and their assembly and installation. Thus, when prepared, they are a principal element in the system configuration baseline and supersede earlier baseline data.

#### **Purpose**

- To document in an identifiable package the necessary instructions for repetitively translating, as desired, the engineering definition into the product defined; includes fabrication, processing, assembly, inspection, and acceptance test directions and procedures as necessary.
- To obtain technical approval of design, fabrication, and delivery of the end product.
- To permit system-level configuration control.

#### **Tools**

- ECAD/ECAE schematic capture and documentation tools.

#### **Inputs**

- System configuration or baseline.
- Drawing trees.
- Design requirements.
- Performance allocations.

#### **Outputs**

- Technical approval of design drawings
- Enabling of system level configuration control and definition.

#### **Where It Fits in the Design Process**

**Phase Application:** Baselined drawings are primarily applicable to the FSD and production and deployment phases. They may also be required for test installations.

**Prerequisite:** Baselining of the design drawings needs to follow baselining of the design requirements and performance allocations and identification of design constraints. This is normally provided via the CI specifications (sec. A4.5.1.2).

#### **Limitations, Deficiencies, Problems**

- Available tools do not effectively address all data management and documentation needs.

#### **A2.5.2.10 Facilities Criteria**

##### **Description**

Facilities criteria documentation developed during design synthesis (sec. A2.3.3.3) must be included in the configuration baseline.

##### **Purpose**

- To define, in terms of the data necessary to govern construction or modification inspection and/or verification, the facilities that become part of, interact with, or support the baseline system
- To establish a basis for acceptance of facilities and for coordinating and evaluating changes involving facilities.

##### **Tools**

- None commercially available.

##### **Inputs**

- Engineering requirements.
- Manufacturing requirements.
- Operational support, test, and training facilities
- Turnover configuration.

##### **Outputs**

- Facilities requirements documents.
- Facilities criteria document.

##### **Where It Fits in the Design Process**

**Phase Application:** For facilities that function as part of, or are necessary to support, system operations, baselining of requirements at a high level may start early in the CE/D phase, with progressive levels of detail "baselined" as required to support development of system elements. The verification baseline must be established at a point that ensures that facility activation supports installation, assembly, or processing of system elements. The verification baseline must also permit (1) evaluation and disposition of any discrepancies occurring during verification and (2) determination of whether any re-verification is required following facility modifications. On programs involving repetitive processing, verifications required prior to or as part of each processing also need to be identified and baselined.

**Prerequisites:** Definition of facility requirements and interfaces

##### **Associated Military Documents**

- MIL-STD-490A, Specification Practices.



### **A2.5.2.11 Installation Drawings**

#### **Description**

System assembly or installation drawings must be included in the configuration baseline. The drawings must include (by reference) assembly, installation, and checkout procedures. Interim configurations for incremental delivery must be included. Upon completion of the work, provision must be made to update the baseline to reflect the as-built configuration if trade skills are involved.

#### **Purpose**

- To establish the configuration of the system element or part to be installed, positioned, and/or interconnected.
- To provide necessary instructions for its installation, including instructions for inspection and functional tests as necessary (by inclusion or reference).
- To define, build, and deliver the end product to the customer and to permit system-level configuration control. As a secondary function, to impose configuration control on CI production and delivery.

#### **Tools**

- MCAD solid and wire-frame modeling tools.
- ECAD/ECAE schematic capture and documentation tools.

#### **Inputs**

- System specification and system description.
- System-level test configurations.

#### **Outputs**

- Installation drawings.
- Support for installation and checkout of configuration items into subsystems and systems.
- Enabling of system-level configuration control.

#### **Where It Fits in the Design Process**

**Phase Application:** Installation drawings are usually baselined near the end of the FSD phase or at the start of the production and deployment phase. They may be required for test installations during earlier phases. They apply to both operating and support systems and installations.

**Prerequisite:** Configuration baseline (sec. A2.5.2) and System Interface Definition (sec. A2.5.2.3).

#### **Limitations, Deficiencies, Problems**

- Available tools not well integrated.
- Available tools do not effectively address all data management and documentation needs.

#### **A2.5.2.12 Technical Data**

##### **Description**

The technical data required to operate and maintain a system must be delivered concurrently with the system increments. A tabulation of the technical data must be considered part of the configuration baseline of the system. This data must be baselined and configuration controlled to match hardware and/or software configurations and changes to them.

##### **Purpose**

- To provide manuals and instructions for training personnel and operating, maintaining, or servicing the system and its elements.

##### **Tools**

- None commercially available.

##### **Inputs**

- System activation.
- Configuration baseline.

##### **Outputs**

- Documentation for training personnel and operating, maintaining, and servicing the system.

##### **Where It Fits in the Design Process**

**Phase Application:** Technical data is usually baselined to match production and to support deployment and/or initial operational test and evaluation (IOT&E). It may be baselined near the end of the FSD phase or partially baselined to support system-level testing and verification.

##### **Limitations, Deficiencies, Problems**

- Available data preparation and management tools do not effectively support all the CALS data management and documentation needs.

##### **Associated Military Documents**

- MIL-STD-38748B.

## **A2.6 OTHER SUPPORTING TASKS AND ANALYSES**

Additional analyses are used in designing electronic circuits and considered to support the basic design process. They are described in this section.

### **A2.6.1 Fault Detection and Fault Isolation**

#### **Description**

Fault detection and fault isolation (FD/FI) analyses are used to determine the effectiveness of the test system in detecting and isolating faults in electronic circuits. This can be accomplished in several ways, but it is usually a manual analysis until the design is sufficiently defined to employ fault simulators and fault graders.

#### **Purpose**

- To determine the effectiveness of the fault detection and fault isolation system, measured in terms of detection coverage and the number of items to which a failure can be isolated.
- To provide data for the creation of maintenance documentation.

#### **Tools**

- Design rule checkers.
- Fault simulators and graders: QuickFault, Hi Low III, SABER.

#### **Inputs**

- System description, including fault detection and handling provisions.
- Test vectors.
- Fault dictionary inputs.
- Failure rates.

#### **Outputs**

- Fault dictionary.
- Fault isolation and detection statistics.
- Fault detection and isolation problem areas.
- Detection stimuli.

#### **Where It Fits in the Design Process**

**Phase Application:** A system-level FD/FI analysis should be completed in the CE/D phase to ensure adequate fault detection and containment provisions have been incorporated into the design. The analysis should be refined during FSD detailed design with the aid of fault simulators and graders.

#### **Limitations, Deficiencies, Problems**

- Unless abstract or simplified fault models are employed, most large scale designs can only be simulated in sections or partially simulated due to their size and complexity. This limitation increases the probability that integration related problems will not be found until breadboard or prototype testing.

## **A2.6.2 False Alarms**

### **Description**

False-alarm analyses are used to determine where false alarms may occur and the probability that a fault detection system will report nonexistent errors.

### **Purpose**

- To verify that the false-alarm rate meets requirements.
- To provide data to correct any problems.

### **Tools**

- None commercially available.

### **Inputs**

- System description.
- Fault detection and fault isolation design.
- Failure modes analysis.

### **Outputs**

- False-alarm problems.

**Phase Application:** Should be conducted as part of the Speciality Engineering Analyses and Evaluations (sec. A2.4.1.3) during CE/D and refined during FSD detailed design.

**Prerequisite:** Design drawings and knowledge of the fault detection and isolation design provisions.

### **A2.6.3 Functional Verification**

#### **Description**

Functional verification is a method of verifying that a design functions according to the design requirements. It involves testing the functionality of the design against the requirements to check compliance.

#### **Purpose**

- To verify that the functionality of electronic designs is correct.
- To find any problems with the design.

#### **Tools**

- Simulators: QuickSim, MSPICE, SABER.

#### **Inputs**

- System and circuit descriptions.
- Test vectors or stimuli.
- ROM code (if any).
- PAL code (if any).

#### **Outputs**

- System and circuit outputs.

#### **Where It Fits in the Design Process**

**Phase Application:** A high-level functional analysis, using higher level models, should be conducted during systems engineering. This analysis should be refined during FSD detailed design by the circuit design engineer.

#### **Limitations, Deficiencies, Problems**

- Unless abstract or simplified fault models are employed, most large scale designs can only be simulated in sections or partially simulated due to their size, complexity, and the mix of analog and digital circuitry. This limitation increases the probability that integration related problems will not be found until the breadboard or prototype testing.
- Functional design errors, mode switching, and other problems may not be uncovered until late in the design cycle because the time to simulate a complete mission is usually prohibitive.

#### **A2.6.4 Testability Analysis**

##### **Description**

A high level testability analysis is used to develop a high level test plan, determine whether the system-level testability requirements can be met, to identify areas of the design that are not easily tested, and to establish BIT/BITE resource allocations.

##### **Purpose**

- To verify that the system-level testability requirements can be met.
- To develop a high level test plan and BIT/BITE allocations.
- To suggest ways of improving the testability of the design.

##### **Tools**

- Design rule checkers.
- Fault simulators and graders: QuickSim, QuickFault, SABER, Copter.

##### **Inputs**

- System and circuit description.
- Operational modes.

##### **Outputs**

- Testability statistics (e.g., percent fault isolation and detection, ambiguity statistics).
- Testability problem areas.
- Suggestions for increasing the testability of the design.

##### **Where It Fits in the Design Process**

**Phase Application:** A high level testability analysis should be conducted as part of the Speciality Engineering Analysis and Evaluations (sec. A2.4.1.3) during CE/D and refined during FSD detailed design. The analysis can be initiated once system-level functional block diagrams and flows have been established and should be performed prior to the Test and Evaluation task (sec. A2.4.2).

##### **Limitations, Deficiencies, Problems**

- Available tools are not sufficiently robust for large scale designs.
- Analysis of simulator results is manual and time consuming.
- Existing tools do not provide the needed data management and documentation capabilities.

## **A3.0 DETAILED DESIGN**

### **A3.1 FUNCTIONAL ANALYSIS AND ALLOCATION**

Functional analysis identifies the characteristic action to be performed by each functional element in the design and the performance requirement for each function to the level of detail required to initiate detailed design and specify required performance for each CI and position. Each function identified is then allocated to a specific circuit or circuit board, to break up the design into manageable parts that can be easily designed.

#### **A3.1.1 Functional Analysis**

##### **Description**

A refinement of the Systems Engineering functional analysis (sec. A2.2).

##### **Purpose**

- To identify and decompose the system-level functional description of the end-item function in a methodical, disciplined analysis.
- To provide traceability of the system and mission objectives and requirements to hardware and software elements.

##### **Tools**

- Specification and requirements capture tools: RDD100 (Ascent Logic).

##### **Inputs**

- Functional specifications and requirements at the CI level.
- Draft CI specifications, part 2.
- Block diagrams.
- ICDs between boards and functions, depending on level.

##### **Outputs**

- Characteristics of board subfunctions.
- Interrelationships between subfunctions.

##### **Where It Fits in the Design Process**

**Phase Application:** Functional analysis for Detailed Design is performed jointly by the Systems Engineering and Detailed Design groups. It should be initiated prior to and performed in conjunction with functional allocation (sec. A3.1.2) and should precede preparation of the final specifications at each level.

**Prerequisites:** System-level baseline (sec. A2.5) definition to the LRU or LRM level.

##### **Limitations, Deficiencies, Problems**

- Available tools not sufficiently robust for large scale programs.
- Available tools not integrated with existing electronic design systems.
- Available tools do not effectively address all data analysis, management, and documentation needs.

### **A3.1.2 Functional Allocation**

#### **Description**

Functional allocation for Detailed Design should be a refinement of the Systems Engineering functional allocations (sec. A3.1.2). Each function generated by the system-level functional analysis is allocated to hardware or software elements (CIs, components, modules), personnel and procedures, external systems, or logistics support subsystems via the system hierarchy (segments, elements, subsystems, etc.). An accounting of the allocation and rationale is maintained.

#### **Purpose**

- To allocate required system and end-item functions to functional areas, hardware and software elements, personnel, procedural controls, external interfaces, or maintenance and support logistics subsystems.
- To maintain an accounting of the allocations made.

#### **Tools**

- Specification and requirements capture tools: RDD100 (Ascent Logic).

#### **Inputs**

- System-level functional block diagrams and flows.
- System and mission requirements.

#### **Outputs**

- Functional allocations.

#### **Where It Fits in the Design Process**

**Phase Application:** Functional allocation for Detailed Design is performed jointly by the Systems Engineering and Detailed Design groups. It should be performed in parallel with a functional analysis at the circuit board level (sec. A3.1.1) and should precede preparation of final specifications.

**Prerequisites:** Systems Engineering functional allocations to the LRU or LRM level (sec. A3.1.2).

#### **Limitations, Deficiencies, Problems**

- Available tools not sufficiently robust for large scale programs.
- Available tools not integrated with existing electronic design systems.
- Available tools do not effectively address all data analysis, management, and documentation needs.



## **A3.2 DESIGN SYNTHESIS**

Detailed design alternatives, test procedures, and detailed specifications are defined that meet the system and CI specifications and requirements.

### **A3.2.1 Design Development**

The tasks described in this section produce the actual design. The system and CI specifications and requirements are evaluated and detailed design alternatives are evaluated until the design either satisfies the specifications and requirements or it is determined that the specifications and requirements can not be met.

#### **A3.2.1.1 Hardware and Software Interface Definition**

##### **Description**

Interfaces between individual circuit boards and board subfunctions are derived and documented. A preliminary cut at the board interfaces based upon system-level considerations is used as a baseline until more detailed circuit level requirements can be identified. Functional analyses and allocations at the circuit board level determine the board interfaces.

##### **Purpose**

- To produce an interface specification to ensure that all separate parts of the design are built to the same specification and that the system maintains its integrity as the design evolves.
- To serve as a basis for follow-on preparation of ICDs.

##### **Tools**

- None commercially available.

##### **Inputs**

- System functional block diagrams, flows, and allocations to circuit level.
- Characteristics of board subfunctions.
- Interrelationships between subfunctions.

##### **Outputs**

- Interface definition for each major design element (e.g., LRU, LRM, circuit board function, software module).

##### **Where It Fits in the Design Process**

**Phase Application:** Although initiated after the functional analyses and allocations, it is performed in conjunction with these analyses.

**Prerequisites:** Baseline system configuration, trade factors from the system-level trade studies (sec. A2.4.1.2), and the results of the engineering speciality analyses (sec. A2.4.1.3). Detailed functional block diagrams and allocations at the circuit board level (sec. A3.1).

### **A3.2.1.2 Trade Studies**

#### **Description**

Trade studies are conducted during detailed design to identify and evaluate design alternatives at the circuit board level. A trade study may be conducted, for example, to determine which of several alternative components or circuit implementations best meets the applicable CI requirements and specifications. Trade studies in support of detailed design are usually not formal studies and often involve data from existing designs.

#### **Purpose**

- To determine the best design methodology, circuitry, and components to use in the design.
- To find the design alternative which best satisfies the requirements and specifications.

#### **Tools**

- None commercially available.

#### **Inputs**

- Characteristics of board subfunctions.
- Interrelationships between subfunctions.
- LRU and board specifications and requirements.
- Draft CI specifications, part 2, block diagrams.
- Budgets for power, reliability, performance, etc.
- Data from previous evaluations of design alternatives (functional tests, timing, electrical, reliability, thermal, layout, FMA, etc.).
- Packaging and board specifications.

#### **Outputs**

- Preliminary circuit schematics.
- Circuit function.
- Block diagrams.
- Theory of operation.
- ICDs.
- Circuit specifications.
- Programmer manuals.
- Throughput analyses.
- Detailed design information.

#### **A3.2.1.2 Trade Studies (concluded)**

##### **Where It Fits in the Design Process**

**Phase Application:** Trade studies are conducted throughout detailed design to identify and select design elements (LRUs, LRMs, circuits, and components) which best meet the CI specification.

##### **Limitations, Deficiencies, Problems**

- Existing design optimization methods and programs are not sufficiently robust for large scale, complex design problems.
- Due to a variety of factors (for example, budget, resource, and time constraints; lack of tools to facilitate trade studies), the cost (in terms of budget, schedule, etc.) of conducting trade studies precludes their use in all but the most critical situations.
- The selection of the "best" design alternative from among several is often based on a consideration of a limited number of parameters, those most readily accessible to or familiar to designer.

### **A3.2.1.3 Design Alternatives**

#### **Description**

Schematics, block diagrams, and other relevant data must be produced to document the design alternatives considered during Detailed Design. Any packaging and layout constraints, such as maximum signal path lengths or components that must be placed close together on board, must be documented. This is the last step in design synthesis and produces a design at the component level.

#### **Purpose**

- To produce the detailed design schematics and data.

#### **Tools**

- MCAD solid and wire-frame modeling tools.
- ECAD/ECAE schematic capture and documentation tools.

#### **Inputs**

- Preliminary circuit schematics.
- Circuit function.
- Block diagrams.
- Theory of operation.
- ICDs.
- Circuit specifications.
- Packaging and board specifications.

#### **Outputs**

- Circuit schematics.
- Circuit function.
- Block diagrams.
- Theory of operation.
- ICDs.
- Circuit specifications.
- Programmer manuals.
- Throughput analyses.
- Released drawings.
- Detailed design information.
- Packaging and layout constraints.
- Parts lists.

### **Where It Fits in the Design Process**

**Phase Application:** This task produces the final design data from all previously produced specifications and requirements.

### **Limitations, Deficiencies, Problems**

- Available tools not well integrated.
- Available tools do not effectively address all data management and documentation needs.

### **A3.2.2 Design Verification**

Design verification is the task of ensuring that all each CI in a design meets all applicable system requirements and specifications. Design elements which do not meet the applicable requirements and specifications may be redesigned if the degree of non-compliance is determined to be unacceptable. The major product of this task is documentation demonstrating the compliance of individual CIs.

#### **A3.2.2.1 Test Procedures Development**

##### **Description**

Test procedures must be developed to verify design compliance, for manufacturing passoff, and for field maintenance. Although the tests are developed to exercise as much of the design as possible, the tests are customized for each use and may differ greatly. Manufacturing tests focus on quality control issues while maintenance tests must efficiently detect and isolate failures that occur in the field.

Typically, manufacturing tests need not be the size and complexity of maintenance tests since they need to only sample the functionality of the manufactured item to verify it has been manufactured correctly.

##### **Purpose**

- To develop test procedures and stimuli for design compliance, manufacturing, and field maintenance.

##### **Tools**

- None commercially available.

##### **Inputs**

- Circuit schematics.
- Circuit function.
- Block diagrams.
- Theory of operation.
- Circuit specifications.
- Programmer manuals.
- LRU and board specifications and requirements for design and testing.

##### **Outputs**

- Test procedures.
- Test stimuli.
- Expected results of tests.
- Areas of design that cannot be tested.

##### **Where It Fits in the Design Process**

**Phase Application:** This task is performed during the detailed design phase. It can be started as soon as preliminary schematics are available.

### **Limitations, Deficiencies, Problems**

- Test development is a manual, time consuming task. The time and resources needed to develop adequate tests for a design are typically underestimated, particularly if the circuit has not been designed to be testable from the onset.
- Automatic test pattern generation (ATPG) is not feasible for most current, large-scale designs due to their size and complexity. ATPG does not work well for microprocessor based designs.
- A high level of fault detection and isolation is difficult to achieve and verify.

### **A3.3 TECHNICAL EVALUATION AND DECISION**

The design is evaluated to check for conformance to the specifications and requirements. The designs are analyzed and problems are corrected or allowed, based on their severity and the cost of fixing them.

#### **A3.3.1 Electrical Stress**

##### **Description**

Electrical stress analysis is used to find power dissipation and current requirements of electronic components. This data is used to predict component reliability.

##### **Purpose**

- To find the power dissipation of electronic devices in order to determine the effects on the reliability of the device.

##### **Tools**

- ECAD simulation tools: MSPICE.

##### **Inputs**

- Detailed circuit description.
- Device specifications.
- Operational data.

##### **Outputs**

- Power dissipation for components.
- Electrical stress for components.

##### **Where It Fits in the Design Process**

**Phase Application:** This analysis is performed during the CD/V and FSD phases by the detailed design engineers once detailed circuit diagrams are available

##### **Limitations, Deficiencies, Problems**

- Most current designs can only be simulated in sections or in part due to their size and complexity and their mix of analog and digital circuitry. Analysis of the results is manual and time consuming.
- Device models for custom circuit elements are often not available due to proprietary, resource, or scheduling reasons
- Available simulators do not effectively address all data management and documentation needs.



### **A3.3.2 Fault Detection and Fault Isolation**

#### **Description**

Ideally these analyses should be a continuation of the fault detection and isolation (FD/FI) analyses initiated during Systems Engineering (sec. A2.6.1). The analyses are used to assess the effectiveness of the provisions incorporated in the design to detect and isolate faults in the system and in individual CIs. The analysis is usually performed on individual circuits with the aid of a fault simulator and a set of test vectors.

#### **Purpose**

- To determine the effectiveness of the system's fault detection and fault isolation capabilities, measured in terms of detection coverage and the number of items to which a failure can be isolated.
- To provide data for the creation of maintenance documentation.

#### **Tools**

- Fault simulators and graders: QuickFault, Hi Low III, SABER.

#### **Inputs**

- Circuit description.
- Test vectors.
- Fault list.
- Failure rates.

#### **Outputs**

- Fault dictionary.
- Detection list.
- Detection stimuli.

#### **Where It Fits in the Design Process**

**Phase Application:** Fault detection and isolation (FD/FI) analyses should be performed during the CD/V and FSD phases by design engineers.

#### **Limitations, Deficiencies, Problems**

- Most current designs can only be simulated in sections or in part due to their size and complexity and the mix of analog and digital circuitry. Analysis of the results is manual and time consuming.
- Device models for custom circuit elements are often not available due to proprietary, resource, or schedule reasons.
- Available simulators do not effectively address all data management and documentation needs.

### **A3.3.3 False Alarms**

#### **Description**

False-alarm analyses are used to ensure that the fault detection provisions incorporated into a design will not result in a incidence of false alarms (false indications of faults or errors) greater than that permitted by the system or CI specification.

#### **Purpose**

- To verify that the false-alarm rate meets requirements.
- To provide data to correct any problems.

#### **Tools**

- None commercially available.

#### **Inputs**

- Circuit description
- Description of the fault detection, isolation, and report provisions.
- Fault detection and isolation statistics.
- Failure modes analysis results.

#### **Outputs**

- Problem areas.
- False-alarm rate.

#### **Where It Fits in the Design Process**

**Phase Application:** This analysis should be performed during the CD/V and FSD phases by the detailed design engineers once detailed test procedures have been defined (sec. A3.3.1) and a fault detection and isolation analysis (sec. A3.3.2).

**Prerequisite:** Circuit schematics and system-level knowledge of the fault detection, fault isolation, and fault reporting provisions.

#### **Limitations, Deficiencies, Problems**

- Manual and time consuming task, often not performed until physical design is complete.

### **A3.3.4 Functional Verification**

#### **Description**

Functional verification is a method of verifying that each element of the design and the design as a whole functions according to the CI and system specifications. The functionality of each individual circuit is simulated and individual CIs and segments are tested to check compliance.

#### **Purpose**

- To verify that the functionality of an electronic design is correct.
- To identify areas of the design not satisfying the specification.

#### **Tools**

- Simulators: QuickSim, MSPICE, SABER.

#### **Inputs**

- Circuit description.
- Test vectors or stimuli.
- ROM code (if any).
- PAL code (if any).

#### **Outputs**

- Circuit outputs.
- Problem areas.

#### **Where It Fits in the Design Process**

**Phase Application:** Functional verification is usually performed during the detailed design process by the circuit designer. It is also possible to perform high-level functional analysis, using higher level models, during the systems engineering phase.

#### **Limitations, Deficiencies, Problems**

- Due to their size and complexity and the mix of analog and digital circuitry, current designs can only be simulated in sections or in part. Integration problems are often not discovered until breadboard or prototype testing.
- Functional, mode switching, and other problems may not be found because designs are not usually simulated over a complete mission cycle due to the length of time required to complete such a simulation run.

### **A3.3.5 Loading Analysis**

#### **Description**

An overloaded device may not be able to drive the connected inputs to a particular level or be able to change output levels fast enough. This can create logic or functional errors in the circuit, affecting the circuit's functional reliability. To prevent these problems, components are derated so that the maximum loading that can be used is less than the physical maximum. This gives a margin of safety in the design so that loading of components is not pushed to the limit, creating problems.

#### **Purpose**

- To calculate the load driven by each component output within a circuit to determine the effect of loading on the functional reliability of the device.
- DC loading analysis: to determine the fanout of each output and its effect on the output's ability to drive to the needed output level.
- AC loading analysis: to determine the capacitive loading on each output to determine effects on timing.

#### **Tools**

- Loading\_\_Analysis (DC only).

#### **Inputs**

- Detailed circuit description (parts list and connection list).
- Device specifications.
- Interface specifications.
- Derating factor.

#### **Outputs**

- Loading of all outputs of each device in the circuit.
- Output loads exceeding derated specifications.

#### **Where It Fits in the Design Process.**

**Phase Application:** This analysis is should be performed during the CD/V phase and refined during the FSD detailed design phase.

#### **Limitations, Deficiencies, Problems**

- Due to their size and complexity and the mix of analog and digital circuitry, current designs can only be analyzed in sections or in part. Integration problems are often not discovered until breadboard or prototype testing.

### **A3.3.6 Preliminary Layout**

#### **Description**

Preliminary layout of components on the board identifies initial board sizing requirements, placement problems, testability, and other information that can help prevent downstream problems. This data can also be used in performing preliminary thermal analysis for reliability.

#### **Purpose**

- To establish a preliminary physical layout.
- To enable spatial, routability, thermal, electrical, mechanical, reliability, testability, maintainability, and environmental requirements to be evaluated early in the design process, when changes can be made to optimize the design.

#### **Tools**

- ECAD PWB design systems: Mentor Package and Board Stations, Intergraph system.

#### **Inputs**

- Circuit description.
- Parts list.
- Board description.
- Layout requirements.
- Electrical requirements.
- Design rules, military specification requirements.

#### **Outputs**

- Preliminary layout.
- Design input to Package Station thermal capability.

#### **Where It Fits in the Design Process**

**Phase Application:** Preliminary layout is performed during the CD/V phase to estimate board-level requirements for the package design. It is also performed during the detailed design phase, when complete part data is available for defining the board-level requirements of the package design.

#### **Limitations, Deficiencies, Problems**

- Existing tools do not provide the needed data management and documentation capabilities.

### **A3.3.7 Testability**

A detailed testability analysis is used to allocate testability resources within the CIs and LRUs, assess the testability of the design, and to ensure that the testability requirements called out in the system and CI specifications have been met.

#### **Purpose**

- Determine and assess the testability of each CI based on testability evaluations of individual design elements (e.g., circuit boards, circuits, components).
- To suggest ways of improving the testability of individual CIs, LRUs, and circuit boards.

#### **Tools**

- Design rule checkers.
- Simulators and fault graders: MSPICE, QuickSim, Copter.

#### **Inputs**

- Circuit description.
- Physical layout.
- Operational modes.

#### **Outputs**

- Testability rating.
- Areas of circuit that are not easily testable.
- Suggestions for increasing the testability.

#### **Where It Fits in the Design Process**

**Phase Application:** This analysis should be performed during the CD/V phase. A detailed testability analysis should be performed once detailed circuit diagrams are available.

#### **Limitations, Deficiencies, Problems**

- Available tools are not sufficiently robust for large scale designs.
- Analysis of simulator and fault grader results is manual and time consuming.
- Existing tools do not provide the needed data management and documentation capabilities.

### **A3.3.8 Worst Case Timing and Critical Path Analysis**

#### **Description**

Worst case timing and critical path analyses are used to determine whether any paths in an electronic design have or could have timing problems. Timing problems can be caused by such things as variations between components, temperature, radiation, etc.

#### **Purpose**

- To determine timing problems in the circuit due to variations in the timing of the devices.
- To determine critical timing paths in designs.

#### **Tools**

- None commercially available.

#### **Inputs**

- Circuit description.
- Operation modes.

#### **Outputs**

- Timing problems in the circuit.
- Critical paths.

#### **Where It Fits in the Design Process**

**Phase Application:** This analysis should be initiated during the CD/V phase for critical items and refined during the FSD detailed design phase.

#### **Limitations, Deficiencies, Problems**

- These analyses are currently manual and time consuming.
- Complex circuits and feedback loops are difficult to analyze.
- Methods using worst case timing for all devices can be overly pessimistic and fail most designs.

## **A4.0 PHYSICAL DESIGN**

Physical design is the packaging of system-level, LRU-level, board-level, and component-level electronics. The following sections summarize these levels of physical design.

### **A4.1 SYSTEM LEVEL PHYSICAL DESIGN**

#### **Description**

System-level physical design involves the packaging of system hardware, envelope, panels, racks, and other hardware.

#### **Purpose**

- To physically design the system to meet spatial, environmental, functional, reliability, and maintainability requirements.

#### **Tools**

- MCAD solid modeling tools: Mentor Package Stations, Intergraph, CimLinc.

#### **Inputs**

- System size, weight, interface, power and thermal, nuclear hardness, survivability, and environment requirements.
- Parts list.
- Trade studies.

#### **Outputs**

- 2D and 3D drawings.
- System physical specifications.
- Interference problems.

#### **Where It Fits in the Design Process**

**Phase Application:** System level physical design is initiated during the proposal phase and refined in subsequent phases of the design process. A comprehensive system-level design should be conducted during the CE/D phase.

#### **Associated Military Documents**

- MIL-STD-454, Standard General Requirements for Electronic Equipment.

#### **Limitations, Deficiencies, Problems**

- Few physical design tools are integrated with electronic design and analysis tools.
- Available tools have limited representation and analysis capabilities.
- Available tools do not effectively address data management and documentation needs.



## **A4.2 LRU/LRM LEVEL PHYSICAL DESIGN**

### **Description**

Hardware line replaceable units (LRU) or modules within the main system hardware must be physically designed.

### **Purpose**

- To physically design modules to meet spatial, environmental, functional, reliability, and maintainability requirements within the system hardware.

### **Tools**

- MCAD solid modeling tools: Mentor Package Stations, Intergraph, CimLinc.

### **Inputs**

- System hardware design specifications.
- LRU size, envelope, weight, interface, power and thermal, nuclear hardness, survivability, and environmental requirements.
- Trade studies.

### **Outputs**

- 2D and 3D drawings.
- Interference problems.
- Board specifications.

### **Where It Fits in the Design Process**

**Application Phase:** LRU/LRM level physical design is initiated during the proposal phase and refined in subsequent phases of the design process. Although a comprehensive system-level design should be conducted during the CE/D phase, most of the detailed design is performed in the FSD phase.

### **Associated Military Documents**

- MIL-STD-1378, Requirements for Employing Standard Electronic Modules.
- MIL-STD-1389, Standard Electronic Modules, Design Requirements for.

### **Limitations, Deficiencies, Problems**

- Few physical design tools are integrated with electronic design and analysis tools.
- Available tools have limited representation and analysis capabilities.
- Available tools do not effectively address data management and documentation needs.

### **A4.3 BOARD LEVEL PHYSICAL DESIGN**

Board-level design involves preliminary layout, layout, routing, and generation of manufacturing data. These operations are summarized in the following sections.

#### **A4.3.1 Preliminary Layout**

##### **Description**

Preliminary layout of components on the board identifies initial board sizing requirements, placement problems, testability, and other information that can help prevent downstream problems. This data can also be used in performing preliminary thermal analysis for reliability.

##### **Purpose**

- To establish a preliminary physical layout.
- To enable spatial, routability, thermal, electrical, mechanical, reliability, testability, maintainability, and environmental requirements to be evaluated early in the design process, when changes can be made to optimize the design.

##### **Tools**

- ECAD Printed Wiring Board (PWB) design systems: Mentor Package and Board Stations, Intergraph system.

##### **Inputs**

- Circuit description.
- Parts list.
- Board description.
- Layout requirements.
- Electrical requirements.
- Design rules, military specification requirements.

##### **Outputs**

- Preliminary layout.
- Design input to Package Stations thermal capability.

##### **Where It Fits in the Design Process**

**Phase Application:** Preliminary layout is performed during the CD/V phase to estimate board-level requirements for the package design. It is also performed during the detailed design phase, when complete part data is available for defining the board-level requirements of the package design.

#### **A4.3.1 Preliminary Layout (concluded)**

##### **Associated Military Documents**

- MIL-STD-275E, Printed Wiring for Electronic Equipment.
- MIL-P-55110, Printed Wiring Boards.
- MIL-P-28809, Printed Wiring Assemblies.

##### **Limitations, Deficiencies, Problems**

- There are currently not many PWB CAD programs that can take electrical requirements into consideration and analyze the resulting component layout.
- There are no direct inputs from circuit simulators of component power dissipation data to thermal layout tools.
- Optimization tools are needed that will optimize component placement, board interconnections, and thermal considerations among all the boards within the LRU.

### **A4.3.2 Layout**

#### **Description**

Layout is the final placement optimization of components on boards within a LRU.

#### **Purpose**

- To place components on boards to meet spatial, routability, thermal, electrical, mechanical, reliability, testability, maintainability, and environmental requirements.

#### **Tools**

- ECAD PWB design systems: Mentor Package and Board Stations, Intergraph system.

#### **Inputs**

- Circuit description.
- Detail parts list.
- Board description.
- Layout requirements.
- Electrical requirements.
- Design rules, military specification requirements.

#### **Outputs**

- Component layout on boards.
- Design input to Package Stations thermal capability.

#### **Where It Fits in the Design Process**

**Phase Application:** Final layout is performed during the detailed design phase, when complete part data is available to define board-level requirements for the package design.

#### **Associated Military Documents**

- MIL-STD-275E, Printed Wiring for Electronic Equipment.
- MIL-P-55110, Printed Wiring Boards.
- MIL-P-28809, Printed Wiring Assemblies.

#### **Limitations, Deficiencies, Problems**

- There are currently not many PWB CAD programs that can take electrical requirements into consideration and analyze the resulting component layout.
- There are no direct inputs from circuit simulators of component power dissipation data to thermal layout tools.
- Optimization tools are needed that will optimize component placement, board interconnections, and thermal considerations among all the boards within the LRU.

### **A4.3.3 Routing**

#### **Description**

Component connections on the various board layers must be optimally routed.

#### **Purpose**

- To optimize routes to meet spatial requirements and electrical requirements for delay times, capacitance, inductance, etc.

#### **Tools**

- ECAD PWB design systems: Mentor Board Stations, Intergraph system.

#### **Inputs**

- Circuit description.
- Parts list.
- Board description.
- Component layout of boards.
- Electrical requirements.
- Design rules, military specification requirements.

#### **Outputs**

- Routed board.
- Design input to manufacturing interface.

#### **Where It Fits in the Design Process**

**Phase Application:** Routing is part of the detailed design process and occurs after the electronics design has been finalized.

#### **Associated Military Documents**

- MIL-STD-275E, Printed Wiring for Electronic Equipment.
- MIL-P-55110, Printed Wiring Boards.
- MIL-P-28809, Printed Wiring Assemblies.

#### **A4.3.3 Routing (concluded)**

##### **Limitations, Deficiencies, Problems**

- Current PWB CAD programs are generally not capable of taking electrical requirements into consideration, analyzing the resulting routing of component connections, or providing electrical data (such as delay times, capacitance, inductance, etc.) to circuit simulators.
- Because of tight schedules that do not allow sufficient time for layout optimization, routing is sometimes started before the layout optimization is complete.
- Design rules in automatic routing programs do not take into consideration electrical requirements, such as delay times, capacitance, inductance, etc.
- The routability analyses performed by most automatic routing programs are often not capable of correctly determining whether a proposed layout can be routed successfully. As a result, engineering manhours and resources are often wasted in an attempt to route layouts that are not routable. The expense of routing boards in which the electrical, thermal, and routability and spatial requirements are optimized can become prohibitive.

#### **A4.3.4 Manufacturing Data Generation**

##### **Description**

The PWB design data must be prepared for manufacturing. This includes generating layer artwork, numerical control drill and trim data, fabrication drawings, military specification test coupons, fabrication-unique patterns (e.g., epoxy flow scallop patterns), and manufacturing board blank layout (optimization of PWB patterns per manufacturing board blank).

##### **Purpose**

- To link CAD processes with CAM processes and hardware.

##### **Tools**

- ECAD PWB design systems: Mentor Board Stations, Intergraph system.

##### **Inputs**

- Board routes.
- Component placement.
- Board definition.
- Board layer stack up.

##### **Outputs**

- Layer artwork.
- Numeric control drill and milling data.
- Fabrication and assembly drawings.
- Military specification test coupons.
- Fabrication-unique patterns.
- Manufacturing board blank layout.

##### **Where It Fits in the Design Process**

**Phase Application:** Generation of manufacturing data occurs in the production phase; however, PWBs may be manufactured as prototypes in the FSD phase.

##### **Associated Military Documents**

- MIL-STD-275E, Printed Wiring for Electronic Equipment.
- MIL-P-55110, Printed Wiring Boards.
- MIL-P-28809, Printed Wiring Assemblies.

##### **Limitations, Deficiencies, Problems**

- Design revisions are costly once manufacturing data has been generated.

## **A4.4 COMPONENT LEVEL PHYSICAL DESIGN**

### **Description**

Physical design at the component level includes the design of custom integrated circuits, gate arrays, and hybrids.

### **Purpose**

- To design functions to fit limited space requirements.

### **Tools**

- IC design systems and tools: Chipgraph Stations.

### **Inputs**

- Circuit and package description.
- Electrical requirements.
- Trade studies.

### **Outputs**

- Semiconductor fabrication description language specific to vendor fabrication house

### **Where It Fits in the Design Process**

**Phase Application:** Semiconductor component design requires long lead times and therefore must be started early in the detailed design phase, if not in the conceptual phase. A commitment must be made early to build a custom IC, and thus to design supporting circuitry around the custom IC.

### **Limitations, Deficiencies, Problems**

- Determining the testability of custom ICs, gate arrays, and hybrids is difficult.
- IC design must be frozen early; changes are expensive and require long lead times.
- Requires computer-intensive capability to fully simulate design.
- IC development libraries are frequently vendor and/or fabrication specific. Changing vendors and/or process technology may require redesign to the specific new vendor or technology process.



## **A4.5 THERMAL ANALYSIS**

### **Description**

Thermal analysis is used to predict component temperatures and thermal stress under a variety of operating conditions. Device power dissipation, cooling, placement, and other information are used to calculate this information.

### **Purpose**

- To determine the need for and the effectiveness of a design's environment control provisions.

### **Tools**

- Thermal analysis tools: AUTOTHERM, THERMAL.

### **Inputs**

- Item description at the circuit board level (e.g., arrangement of circuit boards, external heat sources)
- Power dissipation of each device or group of devices.
- Board and package design (e.g., layout, materials).
- Environmental control provisions (e.g., cooling capacity, location, temperature).

### **Outputs**

- Temperature of each component.
- Problem areas.
- Thermal gradients.

### **Where It Fits in the Design Process**

**Phase Application:** Thermal analyses should begin once the packaging of the circuit is available. Analyses may begin early in the design using simplified models to assist in identifying potential problem areas. Estimates of the board layout and packaging, component power dissipations, and cooling effectiveness are required to perform the analyses.

## **A5.0 RELIABILITY AND MAINTAINABILITY**

### **A5.1 RELIABILITY**

#### **A5.1.1 Failure Modes and Effects Analysis**

##### **Description**

Failure modes and effects analysis (FMEA) is used to determine the effects that failures in a system have on the operation of the system. This determination can be used to produce maintenance procedures, calculate mission success probabilities, etc. The analysis can be done at all levels of design, from system level to individual components.

##### **Purpose**

- To identify the effects of item failures on system operation.
- To ensure no single failure poses a safety problem or will result in the loss of equipment.
- To classify failure effects according to their severity.

##### **Tools**

- None commercially available.

##### **Inputs**

- System definition (e.g., functional block and flow diagrams, circuit diagrams).
- Failure modes and rates.
- Mission function and operational modes.
- Operational information (e.g., duty cycle, environmental conditions).
- Reliability block diagrams.

##### **Outputs**

- FMEA worksheets.
- Failure effects.
- Failure detection method.
- Compensating provisions.
- Severity classification.

##### **Where It Fits in the Design Process**

**Phase Application:** FMEA should be initiated during Systems Engineering, using system-level models, and refined during Detailed Design. An in-depth analysis should be conducted during the CD/V phase.

##### **Limitations, Deficiencies, Problems**

- Currently a manual, time consuming process.

### **A5.1.2 Failure Modes and Effects Criticality Analysis**

#### **Description**

Failure modes and effects criticality analysis (FMECA) is used to rank each potential failure mode identified during FMEA according to its severity and probability of occurrence.

#### **Purpose**

- To identify and rank the most critical failures.

#### **Tools**

- None commercially available.

#### **Inputs**

- Failure effects.
- Failure severity.
- Failure rates and probability.
- Operating time.

#### **Outputs**

- Criticality analysis worksheet.
- Item criticality.
- Criticality matrix.

#### **Where It Fits in the Design Process**

**Phase Application:** FMECA should be initiated during Systems Engineering, using system-level models, and refined during Detailed Design. An in-depth analysis should be conducted once detailed circuit schematics become available.

#### **Limitations, Deficiencies, Problems**

- FMECA is currently a manual, time consuming process.

### **A5.1.3 Fault Tree Analysis**

#### **Description**

Fault tree analysis (FTA) is used to determine the probability of failure of events in a fault tree.

#### **Purpose**

- To determine the probabilities of failure of the events in a fault tree.

#### **Tools**

- Fault tree programs: FTREE, SETS, SEP.

#### **Inputs**

- Failure rates and exposure time.
- Fault tree logic.

#### **Outputs**

- Failure probabilities of fault tree events.

#### **Where It Fits in the Design Process**

**Phase Application:** A fault tree analysis can be performed at any point in the design.

#### **Limitations, Deficiencies, Problems**

- Due to their size and complexity, current designs cannot be modeled within existing fault tree programs unless simplifying assumptions are made or only part of the design is modeled.
- Existing tools do not provide the needed data management and documentation capabilities.

#### **A5.1.4 Mission Analysis**

##### **Description**

Mission success probability is the probability that the system can complete a specified mission. The prediction is a function of the inherent reliability of the design (basic failure rates), the fault tolerance of the design, the mission profile, and other factors.

Operational availability is defined as the ratio of time that the system is operating to the time required to maintain the system in an operational state. The formula is –

$$\text{uptime} / (\text{uptime} + \text{downtime} + \text{repair time} + \text{response time})$$

This differs from inherent availability, which does not include downtime or response time in the calculation.

##### **Purpose**

- To determine the probability of mission completion.
- To predict the availability of the system in order to better estimate the number of system unit needed to complete the mission.

##### **Tools**

- Mission modeling programs: MIREM, CARMA, CEPFRA.

##### **Inputs**

- FMECA inputs.
- MTTR.
- Response times.
- System mission profiles.

##### **Outputs**

- Mission success probability.
- Operational availability.
- Major contributors to system unreliability.

##### **Where It Fits in the Design Process**

**Phase Application:** Mission analyses should be estimated as part of the initial proposal and refined during subsequent phases as part of the system architecture definition. The results of the analysis should be updated as more detailed system and CI design information become available. A comprehensive analysis should be completed prior to finalizing the segment and CI specifications.

##### **Limitations, Deficiencies, Problems**

- Available tools not sufficiently robust for large scale programs.
- Available tools not integrated with electronic design systems.
- Available tools do not provide adequate data management and documentation capabilities.

### **A5.1.5 Reliability Analysis**

#### **Description**

Reliability is the probability that a system, module, or component will operate without failure for specified period of time. Device reliability is calculated from temperature, loading, stress, usage (activity) of device, and other factors. The reliability of the circuit is calculated from the reliability of each component in the circuit, the usage of each device, the fault tolerance of the circuit, and other considerations.

Reliability predictions are used in analyses to validate concepts, verify designs, estimate number of spares, produce maintenance schedules, etc. The failure rate and MTBF are used in the calculation of spares, maintenance timelines, FMECA, mission success probabilities, and MTTR (among other parameters). MTBDE is used to determine the frequency of failures that cause the system to become non-functional and to calculate number of spares required, maintenance timelines, FMECA, mission success probability, MTTR, etc.

#### **Purpose**

- To predict the reliability of an electronic system and various mean time between any failure parameters.

#### **Tools**

- Reliability modeling and prediction programs: STROP, CARMA, CEPFRA, REAP.

#### **Inputs**

- Circuit description.
- Device operating data: electrical stress, temperature, power dissipation, etc.
- Functional description of circuit including a detailed definition of fault-tolerant design.

#### **Outputs**

- MTTF and MTBF of each part.
- MTBF and MTBCF of circuit board or system.

#### **Where It Fits in the Design Process**

**Phase Application:** The reliability of a system should be estimated as part of the initial proposal and refined during the CE/D phase to establish the system architecture. The results of the analysis should be refined in subsequent phases of the design as more detailed system and CI design information become available. A comprehensive analysis should be completed prior to finalizing the segment and CI specifications.

#### **Limitations, Deficiencies, Problems**

- Predictions may not equate to real world failures.
- Available tools not sufficiently robust for large scale programs.
- Available tools not integrated with electronic design systems.
- Available tools do not provide adequate data management and documentation capabilities.

### **A5.1.6 Thermal Analysis**

#### **Description**

Thermal analysis is used to predict component temperatures under a variety of operating conditions for a detailed reliability analysis. Device power dissipation, cooling, placement, and other information are used to calculate the temperature.

#### **Purpose**

- To determine the temperature of each device in the circuit in order to predict component failure rates.

#### **Tools**

- Thermal analysis programs: AUTOTHERM, THERMAL.

#### **Inputs**

- Item description at the circuit board level (e.g., arrangement of circuit boards, external heat sources)
- Power dissipation of each device.
- Board and package design (e.g., layout, materials).
- Environmental control provisions (e.g., cooling capacity, location, temperature).

#### **Outputs**

- Temperature of each component.

#### **Where It Fits in the Design Process**

**Phase Application:** Thermal analysis for reliability analysis is usually performed during the detailed design phase by dedicated thermal analysts. Board layout, packaging description, component power dissipation, and cooling information are required to perform the analysis.

#### **Limitations, Deficiencies, Problems**

- Available tools not sufficiently robust for large scale programs.
- Existing tools do not provide the needed data management and documentation capabilities.

## **A5.2 MAINTAINABILITY**

The following sections describe tasks relating to the maintenance of a system. The results are used to develop procedures for maintaining the system.

### **A5.2.1 Maintainability Allocations and Analyses**

#### **Description**

Maintainability timeline analyses are needed to establish the maintenance schedules for various elements of a system. MTTR, Mmax, and analyses yield predictions of the mean and maximum repair times needed to restore the system to operation. These analyses are based on failure rates, element weights, redundancy and fault-tolerance, maintainability calculations, failure modes, and fault detection capabilities of the system.

#### **Purpose**

- To determine the mean and maximum times needed to repair the system.
- To establish maintenance schedules for the system.

#### **Tools**

- Maintainability prediction programs: AMAP, MEAP.

#### **Inputs**

- System description.
- FD/FI.
- FMA.
- Failure rate data.

#### **Outputs**

- Maintainability parameters: MTTR, MTBMA, Mmax, etc.
- Maintenance schedules.

#### **Where It Fits in the Design Process**

**Phase Application:** The maintainability parameters should be estimated as part of the initial proposal and refined during the CE/D phase to establish the maintenance and support concepts. The results of the analyses should be refined in subsequent phases of the design as more detailed system and CI design information become available. A comprehensive analysis should be completed prior to finalizing the segment and CI specifications.

#### **Limitations, Deficiencies, Problems**

- Available tools not integrated with electronic design systems.
- Available tools do not provide adequate data management and documentation capabilities.



## **A5.2.2 Failure Reporting, Analysis, and Corrective Action System**

### **Description**

The Failure Reporting, Analysis, and Corrective Action System (FRACAS) is used for tracking failures of equipment. It consists of the following functions:

- Collection of removal and failure data in end items.
- Identification of failed assemblies, subassemblies, and parts.
- Identification of the exact part cause of failure.
- Physics of failure analysis, if necessary.
- Corrective action and followup.
- Trend analysis to identify problems.

### **Purpose**

- To collect, catalog, and report failures of equipment to the customer, user, and contractor.

### **Tools**

- None commercially available.

### **Inputs**

- Field reliability and maintainability data.
- Operator comments.

### **Outputs**

- Reliability and maintainability problem areas.
- Actions (e.g., redesign, manufacturing process changes) needed to address problem areas.
- Correlations of field reliability and maintainability data.

### **Where It Fits in the Design Process**

**Application Phase:** Performed as part of extensive field tests or after the system has been deployed.

## **A6.0 LOGISTICS - MAINTENANCE PREDICTIONS**

The following tasks are performed to schedule maintenance and estimate the spares required to meet system availability requirements.

### **A6.1 REPAIR TIME ANALYSIS**

#### **Description**

Repair time analysis evaluates the design to determine the time needed to repair various parts of the system. The analysis is generally performed by a the Logistics Support Analysis group.

#### **Purpose**

- To determine the time to repair the system.
- To predict availability and maintenance schedules.

#### **Tools**

- AMAP.

#### **Inputs**

- System description.
- FD/FI.
- FMA.

#### **Outputs**

- Repair times.

#### **Where It Fits in the Design Process**

**Phase Application:** The analysis should be performed as part of the initial proposal and the results refined during subsequent phases as details for individual LRUs and LRM become available. A comprehensive analysis should be completed prior to finalizing the segment and CI specifications.

#### **Limitations, Deficiencies, Problems**

- Analysis results are often not updated as the design progresses and accurate estimates of repair time are often not available until after the design is finalized.
- Available tools not integrated with electronic design systems.
- Available tools do not provide adequate data management and documentation capabilities.

## **A6.2 MAINTENANCE**

### **Description**

Maintenance evaluates the design to determine maintenance scheduling to meet availability requirements. Data from FMA, FMECA, repair times, and failure rates are used to determine the optimum schedule. The analysis is generally performed by the Logistics Support Analysis group.

### **Purpose**

- To determine maintenance schedules to achieve required level of system availability.

### **Tools**

- None commercially available.

### **Inputs**

- System description.
- Repair times.
- Failure rates.
- FD/FI.
- FMA.
- FMECA.

### **Outputs**

- Maintenance schedules.

### **Where It Fits in the Design Process**

**Phase Application:** The analysis should be performed as part of the initial proposal and the results refined during subsequent phases as details for individual LRUs and LRM become available. A comprehensive analysis should be completed prior to finalizing the segment and CI specifications.

### **Limitations, Deficiencies, Problems**

- Analysis results are often not updated as the design progresses and accurate maintenance schedules are often not available until after the design is finalized.
- Available tools not integrated with electronic design systems.
- Available tools do not provide adequate data management and documentation capabilities.

## **A6.3 SPARES ANALYSIS**

### **Description**

A spares analysis evaluates the description of the system, repair times, failure rates, and basing to determine spares requirements. The analysis is generally performed by the Logistics Support Analysis group.

### **Purpose**

- To determine the number and location of spares needed to achieve specified system availability.

### **Inputs**

- System description.
- Repair times.
- Failure rates.
- Basing data.

### **Outputs**

- Spares data.

### **Where It Fits in the Design Process**

**Phase Application:** Spares requirements should be estimated as part of the initial proposal and refined during subsequent phases as details for individual LRUs and LRMs become available. A comprehensive analysis should be completed prior to finalizing the segment and CI specifications.

### **Limitations, Deficiencies, Problems**

- The spares analysis is often not updated as the design progresses and the requirements are often not determined until after the design is finalized.
- Available tools not integrated with electronic design systems.
- Available tools do not provide adequate data management and documentation capabilities.

## APPENDIX B: DESIGN PROCESS TOOLS

### B1.0 OVERVIEW

This appendix is a sampling of the tools commonly used in the design of electronics. The tools listed are some of the more popular and widely used, although there are many more tools available, including spreadsheets and database management systems.

A select subset of tools with a listing of their important characteristics is shown in table B-1.

Detailed descriptions of the tools follow table B-1. Each description contains several sections describing the important characteristics of the tool, as follows:

- **Description:** Describes the tool.
- **Purpose:** Explains why and when the tool may be used.
- **Analyses Supported:** Lists the types of analyses that the tool supports and an estimated percentage of the task that the tool performs.
- **Inputs:** Lists the major data needed by the tool.
- **Outputs:** Lists the major data that the tool produces.
- **Other Data:** Lists other related data about the tool.
- **Limitations, Deficiencies, Problems:** Where applicable, lists any known information in these areas

Where there is no information under a particular heading, the heading is omitted.

TABLE B-1. Analyses Tool Matrix

Tool	Function	Analyses supported	Inputs	Outputs
RDD100	<ul style="list-style-type: none"> <li>• Functional analysis</li> </ul>	<ul style="list-style-type: none"> <li>• Functional flow analysis</li> <li>• Functional allocation</li> <li>• Performance requirements analysis and allocation</li> </ul>	<ul style="list-style-type: none"> <li>• Functional description of system</li> <li>• Requirements</li> <li>• Data, information, and control flows</li> </ul>	<ul style="list-style-type: none"> <li>• Functional diagrams</li> </ul>
CASA	<ul style="list-style-type: none"> <li>• Life cycle cost</li> </ul>	<ul style="list-style-type: none"> <li>• LCC analysis</li> <li>• Spares analysis.</li> <li>• Operational availability analysis.</li> <li>• Risk and uncertainty analysis.</li> </ul>	<ul style="list-style-type: none"> <li>• System description</li> <li>• LCC data</li> <li>• Risk data</li> </ul>	<ul style="list-style-type: none"> <li>• LCC predictions</li> <li>• Cost drivers</li> <li>• Sensitivity analyses</li> <li>• Risk analysis</li> </ul>
MIREM	<ul style="list-style-type: none"> <li>• Mission and system reliability analysis</li> </ul>	<ul style="list-style-type: none"> <li>• Mission and system reliability</li> <li>• Operational availability</li> </ul>	<ul style="list-style-type: none"> <li>• System functional description</li> <li>• Mission scenario</li> <li>• Reliability and maintainability data</li> </ul>	<ul style="list-style-type: none"> <li>• System reliability and availability</li> <li>• MCSP</li> <li>• MTBCF</li> <li>• Failure resiliency</li> <li>• MTBMA</li> </ul>
AWARE	<ul style="list-style-type: none"> <li>• Failure rate predictor</li> </ul>	<ul style="list-style-type: none"> <li>• Mean time between failures (MTBF)</li> <li>• Mean time between downing events (MTBDE)</li> </ul>	<ul style="list-style-type: none"> <li>• Electronic parts characteristics</li> <li>• Temperature of components</li> <li>• Electrical stress of components</li> </ul>	<ul style="list-style-type: none"> <li>• MTBF of parts</li> <li>• MTBF of assemblies</li> </ul>
CARMA	<ul style="list-style-type: none"> <li>• Reliability predictor</li> </ul>	<ul style="list-style-type: none"> <li>• Mission reliability</li> </ul>	<ul style="list-style-type: none"> <li>• Installation data</li> <li>• Mission phase profile</li> <li>• Assembly duty profile</li> <li>• System configuration</li> <li>• Assembly failure rates</li> </ul>	<ul style="list-style-type: none"> <li>• System reliability</li> <li>• Reports</li> <li>• Reliability block diagrams</li> </ul>
CEPFRA	<ul style="list-style-type: none"> <li>• Reliability and availability predictor</li> </ul>	<ul style="list-style-type: none"> <li>• Reliability</li> <li>• Operational availability</li> </ul>	<ul style="list-style-type: none"> <li>• Failure and/or repair rates</li> <li>• Initial conditions of system in terms of reliability</li> <li>• Mission time for reliability and point and interval availability</li> </ul>	<ul style="list-style-type: none"> <li>• Absorbing process - reliability / MTBF</li> <li>• Ergodic process - availability</li> <li>• Absorbing process - availability</li> </ul>

TABLE B-1. Analyses aTool Matrix (Continued)

Tool	Function	Analyses supported	Inputs	Outputs
REAP	<ul style="list-style-type: none"> <li>Reliability predictor</li> </ul>	<ul style="list-style-type: none"> <li>Reliability</li> <li>Failure rates</li> </ul>	<ul style="list-style-type: none"> <li>MIL-HDBK-217 data</li> <li>Part numbers and reference designators</li> <li>System configuration (drawing tree)</li> </ul>	<ul style="list-style-type: none"> <li>Assembly failure rate breakdown</li> <li>System configuration tree</li> <li>Failure rate versus temperature plot</li> </ul>
RelCalc 2 SysCalc	<ul style="list-style-type: none"> <li>System reliability predictor</li> </ul>	<ul style="list-style-type: none"> <li>System failure rate</li> <li>System MTBF</li> </ul>	<ul style="list-style-type: none"> <li>System configuration data</li> <li>Parts characteristics</li> <li>Parts applications</li> </ul>	<ul style="list-style-type: none"> <li>System failure rate</li> <li>System MTBF</li> </ul>
AMAP	<ul style="list-style-type: none"> <li>Repair time estimator</li> </ul>	<ul style="list-style-type: none"> <li>Mean time to repair (MTTR)</li> <li>Mmax</li> </ul>	<ul style="list-style-type: none"> <li>Description of system</li> <li>Location of maintenance action</li> <li>Quantity of identical SRUs used in the assembly or unit</li> <li>Failure rate for SRU</li> <li>Corrective maintenance data</li> </ul>	<ul style="list-style-type: none"> <li>MTTR</li> <li>Mmax</li> <li>Corrective maintenance timeline</li> </ul>
MEAP	<ul style="list-style-type: none"> <li>Maintainability analysis</li> </ul>	<ul style="list-style-type: none"> <li>MTTR</li> <li>Mean down time</li> <li>Max corrective maintenance time</li> </ul>	<ul style="list-style-type: none"> <li>System description</li> <li>MIL-HDBK-472 data</li> </ul>	<ul style="list-style-type: none"> <li>MTTR</li> <li>Mean down time</li> <li>Max corrective maintenance time</li> </ul>
Quick Fault	<ul style="list-style-type: none"> <li>Fault simulator</li> </ul>	<ul style="list-style-type: none"> <li>Fault detection and fault isolation</li> <li>Failure modes analysis (FMA)</li> <li>Failure modes effects analysis (FMEA)</li> <li>Failure modes criticality analysis (FMECA)</li> <li>Fault tree analysis (FTA)</li> <li>Testability</li> </ul>	<ul style="list-style-type: none"> <li>Circuit description</li> <li>Test vectors (stimulus)</li> <li>Fault list</li> <li>Models</li> </ul>	<ul style="list-style-type: none"> <li>Fault dictionary</li> <li>Detected and undetected faults</li> <li>Detection statistics</li> </ul>
QuickSim	<ul style="list-style-type: none"> <li>Logic simulator</li> </ul>	<ul style="list-style-type: none"> <li>Digital functional verification</li> <li>Nominal timing verification</li> </ul>	<ul style="list-style-type: none"> <li>Circuit schematic (captured with NETED)</li> <li>Test vector (stimulus)</li> <li>Models</li> </ul>	<ul style="list-style-type: none"> <li>Signal list</li> <li>Signal traces</li> </ul>

**TABLE B-1. Analyses Tool Matrix (Concluded)**

Tool	Function	Analyses supported	Inputs	Outputs
SABER	<ul style="list-style-type: none"> <li>• Analog systems simulator</li> </ul>	<ul style="list-style-type: none"> <li>• System-level and analog functional analysis</li> <li>• Worst case analysis</li> </ul>	<ul style="list-style-type: none"> <li>• System description</li> <li>• Test stimulus</li> <li>• Models</li> </ul>	<ul style="list-style-type: none"> <li>• System outputs</li> <li>• Sensitivity analysis result</li> <li>• Fourier results</li> </ul>
MSPICE	<ul style="list-style-type: none"> <li>• Analog simulator</li> </ul>	<ul style="list-style-type: none"> <li>• Analog functional analysis</li> <li>• Worst case analysis</li> <li>• Loading analysis</li> <li>• Power dissipation</li> </ul>	<ul style="list-style-type: none"> <li>• Analog circuit description</li> <li>• Test stimulus</li> <li>• Models</li> </ul>	<ul style="list-style-type: none"> <li>• Data array containing voltages at all nodes for each analysis point</li> <li>• Charts created from node data</li> </ul>
T3	<ul style="list-style-type: none"> <li>• Topological testability checker</li> </ul>	<ul style="list-style-type: none"> <li>• Testability</li> </ul>	<ul style="list-style-type: none"> <li>• Circuit description</li> </ul>	<ul style="list-style-type: none"> <li>• Testability rules not followed</li> </ul>
Package Station (with AutoTherm)	<ul style="list-style-type: none"> <li>• 3-D packaging design including thermal analysis</li> </ul>	<ul style="list-style-type: none"> <li>• 3-D packaging design</li> <li>• Thermal analysis</li> </ul>	<ul style="list-style-type: none"> <li>• Physical board design</li> <li>• Package descriptions and specifications</li> <li>• Component data</li> <li>• Cooling specifications</li> </ul>	<ul style="list-style-type: none"> <li>• Package drawings</li> <li>• Board isothermal maps</li> <li>• Component temperatures</li> </ul>
Board Station (with Layout and Autorouter)	<ul style="list-style-type: none"> <li>• Board layout</li> <li>• Printed wiring board routing</li> </ul>	<ul style="list-style-type: none"> <li>• Physical board layout</li> <li>• Routing</li> </ul>	<ul style="list-style-type: none"> <li>• Component connection list</li> <li>• Parts list</li> <li>• Physical component models</li> <li>• Board description and specification</li> </ul>	<ul style="list-style-type: none"> <li>• Physical board layout and routing</li> <li>• Layer artwork</li> <li>• Assembly and fabrication drawings</li> <li>• Drill data</li> <li>• Layout data for Package Station</li> </ul>



## **B2.0 SYSTEM DESIGN**

### **B2.1 RDD100**

#### **Description**

RDD100 (Requirements Driven Design) assists in capturing and analyzing requirements, function descriptions, and function dependencies.

#### **Purpose**

- To capture and manage the information associated with functional analysis and allocation.

#### **Analyses Supported**

- Functional analysis – 60%.
- Functional allocation – 60%.
- Performance requirements analysis and allocation – 40%.

#### **Inputs**

- Requirements.
- System functional description.
- Data, information, and control flows.

#### **Outputs**

- Functional diagrams.

#### **Other Data**

- Commercial product (Ascent Logic).

## **B2.2 COST EFFECTIVENESS ANALYSIS PROGRAM**

### **Description**

The Cost Effectiveness Analysis Program (CHEAP) performs system cost predictions based on development, acquisition, operation, and support data.

### **Purpose**

- To assess the cost of design alternatives, allowing prediction of life cycle costs from models developed with the system.
- To perform iterative calculations based on changes in reliability, maintainability, spares, inventory management, etc.
- To perform most of the work required for LCC analysis.
- To support trade studies and concept development by giving life cycle costs when required

### **Analyses Supported**

- LCC optimization - 80%.
- Trade studies - 30%.
- Concept development - 5%.

### **Inputs**

- System description.
- LCC data.
- System data on reliability, maintainability, etc.

### **Outputs**

- LCC predictions.

### **Other Data**

- Commercial product.

## **B2.3 CASA**

### **Description**

The Cost Analysis Strategy Assessment (CASA) program provides support for life cycle cost analyses. Life cycle costs are computed based upon research and development, production, and operations and support element costs. Cost can be displayed in a hierarchy, with costs rolled up to any level of detail. CASA contains the following analysis programs:

- LCC – Life cycle cost predictions.
- SENSE – LCC sensitivity analysis.
- RISKMC and RISKOUT – Monte Carlo simulation of LCC.

### **Purpose**

- To support life cycle cost analysis for complex systems with repair.

### **Analyses Supported**

- LCC analysis.

### **Inputs**

- System description.
- LCC data.
- Risk data

### **Outputs**

- LCC predictions.
- Cost drivers.
- Sensitivity analyses.
- Risk analysis.

### **Other Data**

- DoD product.

### **Limitations, Deficiencies, Problems**

- Availability of program currently limited.
- Limited number of LRUs and subsystems can be modeled.
- Not integrated with existing electronic design systems.
- Limited data management and documentation capabilities.

## **B2.4 PROGRAMMED REVIEW OF INFORMATION FOR COSTING AND EVALUATION**

### **Description**

The Programmed Review of Information for Costing and Evaluation (PRICE) is a family of RCA cost prediction models:

- PRICE H – Estimates hardware development and/or production costs.
- PRICE HL – Estimates the cost of operating and maintaining the more complex hardware items and systems.
- PRICE M – Similar to PRICE H, but estimates hardware development and/or production costs for systems composed of small items such as microelectronics.
- PRICE S – Also similar to PRICE H, but estimates development and/or production costs for software.
- PRICE SL – Estimates software maintenance and support costs.
- PRICE Auxiliary Programs – Supports selection of inputs to or processing outputs of PRICE models.

### **Purpose**

- To derive individual or life cycle hardware and software cost estimates.

### **Analyses Supported**

- LCC optimizations – 90%.

### **Inputs**

- PRICE.
  - Electronics weight.
  - Mechanical and structural weight.
  - Densities.
  - Volume.
  - Quantities.
  - Amount of design repetition.
- PRICE H.
  - Unit MTBF.
  - Repair times.
  - Hardware costs.
  - Quantities and learning curves.
  - Test equipment costs.
  - Number of modules and parts per unit.
  - Number of maintenance locations.
  - Transportation.
  - Stockage.

## **B2.4 PROGRAMMED REVIEW OF INFORMATION FOR COSTING AND EVALUATION** (concluded)

- Labor rates.
- Scrap and maintenance concepts.

### **Outputs**

- **PRICE.**
  - Engineering and manufacturing costs.
  - Development and/or production costs.
  - Economic basis of costs.
  - Uncertainty of cost measurements.
- **PRICE H.**
  - Life cycle cost (LCC).
  - Availability and readiness location.
  - Number of test equipment sets.
  - Total costs.

### **Other Data**

- Commercial product.

### **Limitations, Deficiencies, Problems**

- Proprietary programs and algorithms are not available to users.
- PRICE can be used only by subscription with RCA.

## **B3.0 DETAILED DESIGN**

### **B3.1 LOADING \_\_ ANALYSIS**

#### **Description**

Loading \_\_ Analysis is a DC loading analysis tool developed by Boeing.

#### **Purpose**

- To provide DC loadings of the pins of electronic components.

#### **Analyses Supported**

- DC loading analysis - 75%.

#### **Inputs**

- Circuit net list.
- Parts list.
- Component data.

#### **Outputs**

- DC loading of each pin of the electronic components.

#### **Other Data**

- Boeing product.

#### **Limitations, Deficiencies, Problems**

- Only DC loading is provided.
- No AC effects are provided.

## **B3.2 MSPICE**

### **Description**

MSPICE is Mentor's graphical interface to the SPICE analog simulation tool. It is a general-purpose, nonlinear analog circuit simulation tool that performs several types of analyses.

### **Purpose**

- To perform four types of analyses: DC operating point, DC sweep, AC sweep, and transient.

### **Analyses Supported**

- Analog functional analysis – 50%.
- Worst case analysis - 25%.
- Loading analysis – 25%.
- Power dissipation – 50%.

### **Inputs**

- Analog circuit (captured with NETED or described in a standard SPICE deck).
- Test stimuli (voltage and current forces).
- Models.

### **Outputs**

- Data array containing voltages at all nodes for each analysis point.
- Charts created from node data.

### **Other Data**

- Commercial product.

### **Limitations, Deficiencies, Problems**

- Slow; simulation time increases greatly for large circuits, circuits with feedback, or switching circuits with many transitions.
- Loading analysis is not a built-in function, but can be accomplished by manual calculations from analysis results.
- When performing functional verification and power dissipation analyses, the user must manually look at every component and check the results.

### **B3.3 QUICKSIM**

#### **Description**

QuickSim is an interactive logic simulator that allows the verification of functionality of electronic designs. The design must be captured with NETED, a schematic capture tool.

#### **Purpose**

- To verify the logic functionality of designs.
- To verify circuit timing.

#### **Analyses Supported**

- Digital functional verification – 75%.
- Nominal timing verification – 50%.

#### **Inputs**

- Circuit schematic (captured with NETED).
- Test vectors (stimuli).
- Device models.

#### **Outputs**

- Signal list.
- Signal traces.

#### **Other Data**

- Commercial product.

#### **Limitations, Deficiencies, Problems**

- The design must be captured with NETED, a schematic capture tool.



### **B3.4 SABER**

#### **Description**

SABER is an analog system simulation tool for electronic, hydraulic, mechanical, and other systems. SABER simulates the response of a given system and input stimuli for DC, transient, and frequency domains. It performs several types of analyses, including DC, DC sweep, transient, frequency sweep, noise, Fourier, and sensitivity, and has a graphics interface for charting analysis results.

#### **Purpose**

- To simulate and verify analog systems.
- To support behavioral level modeling, as well as network and equivalent circuit modeling.

#### **Analyses Supported**

- System-level functional analysis – 25%.
- Analog functional analysis – 75%.
- Worst case analysis – 25%.

#### **Inputs**

- System description.
- Test stimuli.
- Models.

#### **Outputs**

- System outputs.
- Sensitivity analysis result.
- Fourier results.

#### **Other Data**

- Commercial product.

#### **Limitations, Deficiencies, Problems**

- SABER is not integrated with other electronic design tools.
- Device models are difficult to create.
- Graphical interface lacking.
- System description and models must be entered as text files.

## **B4.0 PHYSICAL DESIGN**

### **B4.1 BOARD STATION**

#### **Description**

Board Station is a physical design tool for printed wiring boards. It supports automatic layout and routing.

#### **Purpose**

- To lay out and route printed wiring boards.

#### **Analyses Supported**

- Physical board layout – 95%.
- Routing – 50%.

#### **Inputs**

- Component connection list.
- Parts list.
- Physical component models.
- Board description and specification.

#### **Outputs**

- Physical board layout and routing.
- Layer artwork.
- Assembly and fabrication drawings.
- Drill data.
- Layout data for Package Station.

#### **Other Data**

- Commercial product.

#### **Limitations, Deficiencies, Problems**

- Board Station does not support simulation tools with layout-dependent data for analyses of capacitance, resistance, and cross-coupling of board routes.

## **B4.2 INTERGRAPH PWB SYSTEM**

### **Description**

The Intergraph PWB system is used for printed wiring board and printed wiring assembly design, including surface mount (SMT), boards, hybrid packages, discrete wire routing (multiwire), very large PWB/PWA boards, and combinations of these technologies. The system provides interactive layout of components and connection for physical design, using part and connection data extracted from schematics developed on other tools combined with physical component data from libraries.

### **Purpose**

- To perform automatic or manual component placement and optimization and autorouting of PWBs.

### **Analyses Supported**

- Component placement – 90%.
- Routing – 50%.

### **Inputs**

- Logic schematic.
- Connection list.
- Parts list.
- Component and board geometry models.

### **Outputs**

- Layer artwork.
- Assembly and fabrication drawings.
- Back annotation schematic data.

### **Other Data**

- Commercial product.

### **Limitations, Deficiencies, Problems**

- Maximum file size of 300M, 15-layer board does not support simulation tools with layout-dependent data such as capacitance and resistance of traces or cross coupling, etc.

### **B4.3 PACKAGE STATION**

#### **Description**

The Package Station system from Mentor consists of a 3D CAD drafting tool and a thermal analysis tool. The drafting tool inputs 3D package designs for manufacturing or input into the thermal analysis tool of EPAD. The thermal analysis tool uses layout, cooling, and heat generation data to compute component and board temperatures over a 2D surface.

#### **Purpose**

- To input 3D package designs and compute component temperatures for failure rate analysis.

#### **Analyses Supported**

- Thermal analysis – 80%.
- 3D packaging design – 10%.

#### **Inputs**

- Physical board design (board layout, etc.).
- Package description and specifications.
- Component data (power dissipations, etc.).
- Cooling specifications.

#### **Outputs**

- Package drawings.
- Board isothermal maps.
- Component temperatures.

#### **Other Data**

- Commercial product.

#### **Limitations, Deficiencies, Problems**

- The thermal analysis tool currently handles only 2D surfaces.

## **B5.0 RELIABILITY**

### **B5.1 MIREM**

#### **Description**

The MIREM (Mission Reliability Model) program assists in the evaluation of mission reliability and availability for systems incorporating fault-tolerant features such as redundancy and dynamic reconfigurability.

#### **Purpose**

- To assist in the evaluation of systems incorporating fault-tolerant design features.

#### **Analyses Supported**

- Mission and system reliability - 80%.
- Operational availability - 80%.

#### **Inputs**

- System functional description.
- Mission scenario
- Reliability and maintainability data (e.g., failure rates, repair rates).

#### **Outputs**

- System reliability and availability.
- Mission Completion Success Probability (MCSP)
- Mean Time Between Critical Failures (MTBCF).
- Failure resiliency.
- Mean time between maintenance actions (MTBMA)

#### **Other Data**

- DoD product

#### **Limitations, Deficiencies, Problems**

- Size and complexity of systems that can be modeled is limited.
- Limited data management and documentation capabilities.
- Not integrated with existing electronic design systems or analysis tools.

## **B5.2 AVIONICS WORKSTATION AUTOMATED RELIABILITY ESTIMATOR**

### **Description**

The Avionics Workstation Automated Reliability Estimator (AWARE) provides a fully automated capability to perform MIL-HDBK-217E stress method failure rate predictions of electronic equipment. It analyzes a single assembly selected by the user, with results available for maintainability and system reliability analysis.

### **Purpose**

- To predict the failure rate of electrical and electronic parts and assemblies in accordance with the stress analysis method of MIL-HDBK-217E.

### **Analyses Supported**

- MTBF - 90%.
- MTBDE - 90%.

### **Inputs**

- Electronic parts characteristics.
- Temperature of components.
- Electrical stress of components.

### **Outputs**

- MTBF of parts.
- MTBF of assemblies.

### **Other Data**

- Boeing product.

### **Limitations, Deficiencies, Problems**

- Limited to a single circuit board at a time.
- Assembly failure rates cannot be accumulated.
- Serial MTBF computation only; redundancy and error detection are not considered.
- Batch only operation, no interactive interface.
- Limited to Apollo and Mentor workstations.

### **B5.3 COMPUTER-AIDED RELIABILITY MODELING ANALYSIS**

#### **Description**

Computer-Aided Reliability Modeling Analysis (CARMA) is a general-purpose program for mission reliability modeling and prediction of complex systems. It is one of a family of standard automated reliability, maintainability, and availability analysis tools being developed under the direction of the Boeing Aerospace Product Support organization.

#### **Purpose**

- To perform a reliability prediction for each subsystem listed in the system configuration data.
- To perform global predictions on all listed subsystems or selected subsystem predictions based on user inputs.
- To calculate system reliability on a per mission phase basis, including dependency from one mission to the next.

#### **Analyses Supported**

- Mission reliability - 50% to 80%.

#### **Inputs**

- Installation data.
- Mission phase profile.
- Assembly duty profile.
- System configuration.
- Assembly failure rates.

#### **Outputs**

- System reliability.
- Reports.
- Reliability block diagrams.

#### **Other Data**

- Boeing product

## **B5.4 COMPUTERIZED EVALUATION PROGRAM FOR RELIABILITY/AVAILABILITY**

### **Description**

The Computerized Evaluation Program for Reliability/Availability (CEPFRA) solves a large class of reliability and availability evaluation problems that can be formulated as Markov processes.

### **Purpose**

- To solve reliability and availability evaluation problems where the underlying failure and repair times can be characterized by exponential distribution.

### **Analyses Supported**

- Reliability - 60%.
- Operational availability - 60%.

### **Inputs**

- Failure and/or repair rates.
- Initial conditions of system reliability.
- Mission time for reliability and point and interval availability.

### **Outputs**

- Absorbing process - reliability and MTBF.
- Ergodic process - availability.
- Absorbing process - availability.

### **Other Data**

- Commercial product.

### **Limitations, Deficiencies, Problems**

- Maximum number of states is limited to 30 on the mainframe version and 99 on the PC version.
- The PC version does not produce availability outputs.



## **B5.5 RELCALC 2 AND SYSCALC**

### **Description**

RelCalc 2 and SysCalc allow definition of a modular, hierarchical system model used to perform the part stress reliability prediction procedure of MIL-HDBK-217D and E.

### **Purpose**

- To provide a set of system-level functions that allows definition of a modular, hierarchical system.
- To automate the part stress reliability prediction procedure of MIL-HDBK-217D and E.
- To create and maintain a system made up of circuits.
- To perform the system-level reliability prediction calculations for the current system and output the results, including system failure rate and MTBF for the system model.

### **Analyses Supported**

- System failure rate - 60% to 75%.
- System MTBF - 60% to 75%.

### **Inputs**

- System configuration data.
- Parts characteristics.
- Parts applications.

### **Outputs**

- System failure rate.
- System MTBF

### **Other Data**

- Commercial product.

### **Limitations, Deficiencies, Problems**

- These tools are limited to redundant configurations no more complex than K-of-N identical blocks.
- There is no provision for fault coverage input.
- Temperature rise must be input directly.
- A workaround procedure is used to implement 217E.
- Limited to a maximum of 50 modules, except K may range to 500 in a K-of-N module.
- Not all part types are included in the model.

## **B5.6 RELIABILITY EFFECTIVENESS ANALYSIS PROGRAM**

### **Description**

The Reliability Effectiveness Analysis Program (REAP) provides the ability to perform reliability predictions based on the techniques and data contained in MIL-HDBK-217.

### **Purpose**

- To predict failure rates for components, assemblies, and systems.

### **Analyses Supported**

- Reliability - 75%.
- Failure rates - 75%.

### **Inputs**

- MIL-HDBK-217 data.
- Part numbers and reference designators.
- System configuration (drawing tree).

### **Outputs**

- Assembly failure rate breakdown
- System configuration tree.
- Failure rate versus temperature plot

### **Other Data**

- Commercial product.

## **B5.7 SINGLE-THREAD RELIABILITY OPTIMIZATION PROGRAM**

### **Description**

The Single-Thread Reliability Optimization Program (STROP) optimizes systems design. Starting with a single thread (nonredundant) system, it sequences redundant additions to the system in accordance with the maximum ratio of incremental improvement in system reliability with respect to the incremental increase in system weight (DR/DW). STROP also predicts the weight (or cost) required to meet a given reliability goal or the maximum reliability that can be achieved within given weight and cost constraints.

### **Purpose**

- To perform reliability versus weight optimizations on defined single-thread system configurations (i.e., long-term, unmanned spacecraft).

### **Analyses Supported**

- Reliability versus weight optimization - 50%.

### **Inputs**

- Single-thread component block identification.
- Block configuration and number of components in block.
- Redundancy addition class.
- Failure rates.
- Block weight and redundancy addition weight.
- Duty cycle.
- Mission time.
- Constraints.

### **Outputs**

- Mission time and reliability and weight constraints.
- System cost.

### **Other Data**

- Boeing product.

## **B5.8 RPP**

### **Description**

RPP provides failure rate predictions of electronic equipment.

### **Purpose**

- To predict the failure rate of electrical and electronic parts and assemblies in accordance with the stress analysis method of MIL-HDBK-217E.

### **Analyses Supported**

- MTBF - 70%.
- MTBDE - 70%.

### **Inputs**

- Electronic parts characteristics.
- Temperature of components.
- Electrical stress of components.

### **Outputs**

- MTBF of parts.
- MTBF of assemblies.
- MTBDE.

### **Other Data**

- Boeing product.

## **B5.9 SINDA**

### **Description**

Sinda is a general-purpose thermal analysis program that is based on a 3D finite difference model supplied by the user. It analyzes conduction, convection, and radiation modes of heat transfer as well as incompressible fluid flow in ducts. A finite difference model representative of the physical entity is required. The model must define the finite difference nodes, their thermal connectivity, and thermal conductance values.

### **Purpose**

To analyze the complete domain of heat transfer situations encountered in electronic equipment.

### **Analyses Supported**

- Steady-state thermal analysis – 100%.
- Transient thermal analysis – 100%.

### **Inputs**

- Thermal model.
- Cooling specifications.
- Circuit description.

### **Outputs**

- Nodal temperatures.
- Conductance values.

### **Other Data**

- Public domain program developed by NASA.

### **Limitations, Deficiencies, Problems**

- Because Sinda supports incorporation of user-supplied Fortran code, it is limited only by the user.
- Sinda does not support graphics input or problem definition.
- This tool requires development of finite difference thermal models that incorporate design parameters for tailoring the model to a particular physical instance of the entity for which the model was created.

## **B5.10 THERMAL EFFECTIVENESS ANALYSIS PROGRAM**

### **Description**

The Thermal Effectiveness Analysis Program (THERMAL) predicts thermal characteristics of circuit boards and analyzes the board for convective heat transfer to predict component and junction temperatures.

### **Purpose**

- To predict electronic component temperatures on circuit boards.

### **Analyses Supported**

- Thermal (convective) – 80%.

### **Inputs**

- Physical layout.
- Power dissipation.
- Cooling data.

### **Outputs**

- Component temperatures.

### **Other Data**

- Commercial product.

### **Limitations, Deficiencies, Problems**

- THERMAL is restricted to convective heat transfer, which is insignificant in avionics.

## **B5.11 AUTOTHERM (MENTOR PACKAGE STATION TOOL)**

### **Description**

Autotherm is a thermal analysis tool integrated with Mentor Package Station. It uses layout, cooling, and heat generation data to compute component and board temperatures over a 2D surface.

### **Purpose**

- To compute component temperatures for thermal and failure rate analysis.

### **Analyses Supported**

- Thermal analysis ~ 80%.

### **Inputs**

- Physical board design (board layout, etc.).
- Package description and specifications.
- Component data (power dissipation, etc.).
- Cooling specifications.

### **Outputs**

- Board isothermal maps.
- Component temperatures.

### **Other Data**

- Commercial product.

### **Limitations, Deficiencies, Problems**

- Currently handles only 2D surfaces.

## **B6.0 MAINTAINABILITY**

### **B6.1 AUTOMATED MAINTAINABILITY ANALYSIS PROGRAM**

#### **Description**

The Automated Maintainability Analysis Program (AMAP) is an application of the SMART software package that helps automate maintainability analysis.

#### **Purpose**

- To input, organize, and store maintenance data.
- To structure the data entered and create an electronic worksheet that allows the user to calculate the MTTR and Mmax and to create corrective maintenance timelines.

#### **Analyses Supported**

- MTTR - 80%.
- Mmax - 80%.

#### **Inputs**

- Description of system.
- Location of maintenance action.
- Quantity of identical SRUs used in the assembly or LRU.
- Failure rate for SRU.
- Additional inputs dealing with corrective maintenance.

#### **Outputs**

- MTTR.
- Mmax.
- Corrective maintenance timeline.

#### **Other Data**

- Boeing product.

#### **Limitations, Deficiencies, Problems**

- AMAP must be tailored to each project by changing code.
- Only one assembly can be calculated at a time.
- The program does not accumulate system estimates.
- There are a maximum of 25 subtasks per SRU record.



## **B6.2 MAINTAINABILITY EFFECTIVENESS ANALYSIS PROGRAM**

### **Description**

The Maintainability Effectiveness Analysis Program (MEAP) performs serviceability evaluations on electronic and electromechanical systems based on MIL-HDBK-472.

### **Purpose**

- To perform MTTR, mean downtime, and maximum corrective maintenance calculations at each maintenance level.

### **Analyses Supported**

- MTTR - 75%.
- Mean downtime (MDT) - 75%.
- Maximum corrective maintenance (Mctmax) - 75%.

### **Inputs**

- System description.
- MIL-HDBK-472 data.

### **Outputs**

- MTTR.
- Mean downtime (MDT).
- Maximum corrective maintenance time (Mctmax).

### **Other Data**

- Commercial product.

## **B6.3 GENERALIZED RELIABILITY AND MAINTAINABILITY PROGRAM**

### **Description**

GRAMP is a set of computer programs for modeling fault tolerant complex systems, allowing for repair.

### **Purpose**

- Reliability, maintainability, and availability predictions to support allocations and evaluations.
- LSA/LCC analysis.

### **Analyses Supported**

- Markov model used as basis for reliability, maintainability, and life cycle cost analysis.

### **Inputs**

- System description and architecture (e.g., block diagrams).
- Failure rates, repair times, etc.

### **Outputs**

- Reliability, availability, block diagrams

### **Other Data**

- Commercial product.

### **Limitations, Deficiencies, Problems**

- Size and complexity of systems that can be modeled is limited.
- Limited data management and documentation capabilities.
- Not integrated with existing electronic design systems or analysis tools.

## **B7.0 TESTABILITY**

### **B7.1 COPTER**

#### **Description**

Copter is an observability and controllability analyzer for ASICs. The ratings can be used to assess the work required to increase design testability.

#### **Purpose**

To determine the observability and controllability of an ASIC for testability.

#### **Analyses Supported**

- Testability - 10%.

#### **Inputs**

- Circuit description.

#### **Outputs**

- Observability and controllability ratings.

#### **Other Data**

- Commercial product.

#### **Limitations, Deficiencies, Problems**

- Copter works only for ASICs designs.

## **B7.2 QUICKFAULT**

### **Description**

QuickFault is an interactive simulator that can operate as a fault simulator or as a logic simulator. In fault mode, it is an interactive, concurrent fault simulator that allows grading a set of test vectors to determine how effectively they detect and isolate faults.

### **Purpose**

- To test how effectively a set of test vectors detects and isolates faults or defects in a digital circuit.

### **Analyses Supported**

- Fault detection and isolation - 90%.
- FMA - 50%.
- FMEA - 50%.
- FMECA - 50%.
- FTA - 30%.
- Testability - 25%.

### **Inputs**

- Circuit description.
- Test vectors (stimuli).
- Fault list.

### **Outputs**

- Fault dictionary.
- Detection list.
- Detection statistics.

### **Other Data**

- Commercial product.

### **Limitations, Deficiencies, Problems**

- Not sufficiently robust for large scale designs.

### **B7.3 T3**

#### **Description**

T3 is a topological testability checker that checks a design for a limited number of topological testability design rules and gives error messages, noting areas that violate the design rules.

#### **Purpose**

To check a design for testability and show errors

#### **Analyses Supported**

- Testability - 10%.

#### **Inputs**

- Circuit description.

#### **Outputs**

- Testability rules not followed.

#### **Other Data**

- Boeing product

#### **Limitations, Deficiencies, Problems**

- Only topological testability rules are checked
- Limited number of testability design rules.

## **B7.4 WIRING INFORMATION AND RELEASE SYSTEM**

### **Description**

The Wiring Information and Release System (WIRS), an IMS system, accommodates the definition of wiring systems. It develops automated tests and electromagnetic pulse analysis for wiring bundles.

### **Purpose**

- To integrate the design/build process.
- To control the release of information used for the design, manufacture, installation, and testing of airplane wire bundles.
- To develop tests and perform analyses.

### **Analyses Supported**

- Wiring test generation - 90%.
- Electromagnetic pulse analysis - 100%.

### **Inputs**

- Wire bundle assembly, diagram, and equipment data
- Mockup data.
- Planning data.

### **Outputs**

- Test for manufacturing tester.
- Pulse analysis results.
- Design and planning error diagnostics.
- Shop aids, reports, and materials
- Installation instructions.

### **Other Data**

- Boeing product.

## **B8.0 DOCUMENTATION PREPARATION**

### **B8.1 GENERAL PURPOSE DOCUMENTATION PROGRAMS**

#### **Description**

General-purpose documentation programs can be employed to document the results of any task or analysis.

#### **Purpose**

- Documentation preparation.

#### **Analyses Supported**

- All

#### **Inputs**

- Tabular data.
- Textual data.

#### **Outputs**

- Documentation.

#### **Other Data**

- Commercial products.

#### **Limitations, Deficiencies, Problems**

- Not integrated with existing design systems or tools, manual management and formatting of information required.

## **B8.2 MENTOR DOC PROGRAM**

### **Description**

DOC is a general-purpose word processor and document editor.

### **Purpose**

- To prepare reports and other forms of documentation.

### **Analyses Supported**

- Documentation - 90%.
- Reports - 90%.

### **Inputs**

- Text.
- Graphics.

### **Outputs**

- Documents.
- Reports
- Tables.

### **Other Data**

- Commercial product.

### **Limitations, Deficiencies, Problems**

- Graphics must be in a Mentor format.



## **B9.0 GENERAL PURPOSE SPREADSHEET PROGRAMS**

### **Description**

General-purpose spreadsheet programs can be programmed to compute many of the design parameters required as part of the design analyses described in Appendix A.

### **Purpose**

- General purpose computing support for a variety of design tasks and analyses.

### **Analyses Supported (examples)**

- LCC optimization – 20%.
- FMECA – 20%.
- Reliability – 50%.
- Failure rate, MTBF, MTBDE – 70%.
- Maintenance timeline, MTTR, Mmax – 40%.
- FD/FI – 10%.
- FRACAS – 15%.

### **Inputs**

- Tabular data.
- Algorithms.

### **Outputs**

- Tabular data.

### **Other Data**

- Commercial products.

### **Limitations, Deficiencies, Problems**

- Not integrated with existing design systems or tools, manual management and formatting of data required.
- Available tools have limited representation, analysis, documentation, and data management capabilities.